THE SCIENCE-HISTORY OF THE UNIVERSE

VOLUME III

PHYSICS

By GEO. MATTHEW

ELECTRICITY

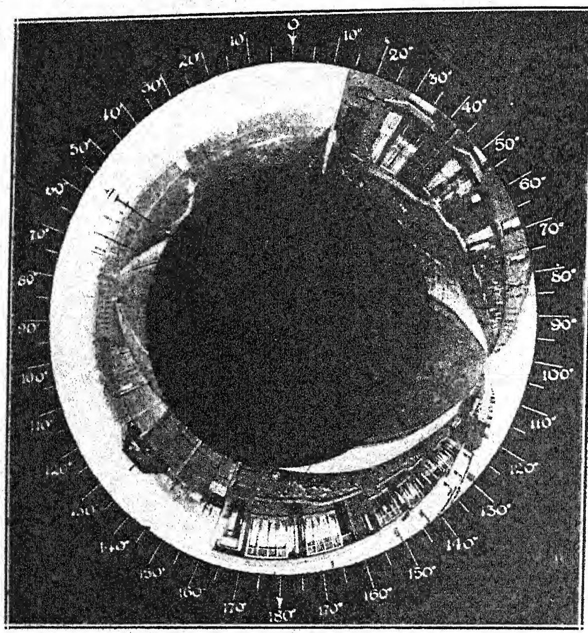
By PROFESSOR WM. J. MOORE

THE SCIENCE-HISTORY OF THE UNIVERSE

FRANCIS ROLT-WHEELER
MANAGING EDITOR

IN TEN VOLUMES

THE CURRENT LITERATURE PUBLISHING COMPANY
NEW YORK
1910



"THE EYE OF THE SUBMARINE."

The improved periscope, showing all directions at one glance. At sea, where the aim is to locate a vessel, the distortion is less disturbing.

THE SCIENCE-HISTORY OF THE UNIVERSE

INTRODUCTIONS BY

PROFESSOR E. E. BARNARD, A.M., Sc.D.,
Yerkes Astronomical Observatory.

PROFESSOR CHARLES BASKERVILLE, Ph.D., F.C.S.,
Professor of Chemistry, College of the City of New York.

DIRECTOR WILLIAM T. HORNADAY, Sc.D.,
President of New York Zoölogical Society.

PROFESSOR FREDERICK STARR, S.B., S.M., Ph.D.,
Professor of Anthropology, Chicago University.

PROFESSOR CASSIUS J. KEYSER, B.S., A.M., Ph.D.,
Adrian Professor of Mathematics, Columbia University.

EDWARD J. WHEELER, A.M., Litt.D.,
Editor of "Current Literature."

PROFESSOR HUGO MUENSTERBERG, A.B., M.D., Ph.D., LL.D.,
Professor of Psychology, Harvard University.

CONTENTS

ELECTRICITY

PHYSICS

CHAPTER I

AN ANALYSIS OF MATTER

WHEN a child first opens his eyes on the world about him a confusing array of experiences thrust themselves upon his notice. The clothes in which he is wrapped, the incomprehensible voice-sounds that come to his ears, the ever-changing personalities of his environment—everything is wonderful, strange and fearsome because of its strangeness. So must the world of nature have seemed strange to early man, strange and terrifying. The sights and sounds of the forest, the wind rushing through the trees or lashing the rivers into foam, thunder and clouds and lightning, clear sun and quiet stars—all spoke to man in his earlier development in personal voices. Each new object of sense constituted for him an object for suspicious investigation or superstitious fear. Familiarity may or may not breed contempt, but that it does induce a form of indifference is certain.

When a leaf rustles in the forest to-day, the rational explanation of a breath of wind takes the place of the old-time fear of a wood-demon; when a tidal wave rushes up a river, the modern knowledge of tides releases man from a blind terror. And this goes even farther, for when a lightning-flash strikes, the law of the association of ideas will lead the mind to correlate the incident with Benjamin Franklin and with the harnessing of the lightning to many

everyday uses. Having passed the stage of superstitious wonder, man at once attempts to classify the phenomena of nature among those experiences of whose character already he feels himself sure.

The earliest recorded beginnings of physical science were made, so far as history can testify, by the Chaldean astrologers. Their study of the stars, however, directed as it was rather to the prediction of individual and national destinies than to determining the real nature of the material universe, laid the ground-work for further study, but bequeathed little of practical importance in physics.

No great names in science have been bequeathed to the world by Assyria or Chaldea. They may have furnished material for the imaginative genius of the Greeks, but the latter alone were capable of formulating into a system the vague wisdom of the Orient. As John Lord remarks, "The East never gave valuable knowledge to the West; it gave the tendency to Egyptian mysticism, which in its turn tended to superstition. Instead of astronomy, it gave astrology; instead of science, it gave magic, incantations and dreams."

The Chaldean and Assyrian civilizations which gave birth to the astrology of the Magi flourished and declined in the fertile valleys of the Tigris and Euphrates. Nearly a thousand years before them, however, there had been developing in the fecund region of the Nile the people who produced the first of those marvelous pyramids which remain to-day the greatest monuments of history. Some considerable knowledge of physics and the elementary application of machines the Egyptians must have possessed, or at least the builders of the pyramids, whoever they were. The stones are much larger than those used in architecture to-day. The columns of the Egyptian temples still standing in ruins are immense. Travelers look with astonishment and admiration at the gigantic structures whose walls, lintels, columns and entablatures are formed of material cut in extraordinary dimensions. No

scientific works remain to show how the ancient builders of Egypt managed to carry and put in place such large blocks of stone. Mural paintings, sculptures and inscriptions are the only means of conveying such slight information as has been handed down to the present generation.

It has been held by some students of antiquity that the pyramids were designed as institutions to embody cosmic discoveries; for example, that certain specific measurements of the structure bear a definite ratio to such matters as the exact length of the earth's circumference and diameter, the length of an arc of meridian and standard units of measure. Other theorists, with far more probability in their favor, believe the pyramids to have been constructed as the tombs of the great kings whose names are graven in the interior and whose sarcophagi (with their mummies) are often found in the central chamber. Still others have declared that the pyramids were used for astronomical study.

Whatever other purpose the pyramids may have served, they seem to have been little adapted for observatories. It is a matter of common knowledge that an object viewed through a roll of paper is better seen in detail than when looked at without such aid. Place a lens in either end of the roll, adjust the focus of the lenses and a telescope is made. The eye takes in a great deal more than the mind perceives. In gazing at an object, especially at a distance, the detail of the object is obscured by the light reflected from hundreds of other objects in the neighborhood. The simple roll of paper overcomes this difficulty in exactly the same way that the ventilating passages, the so-called "telescopes" of the pyramids, might do. A star is visible in broad daylight when viewed through such a long, narrow passage as were these nine-inch "telescopes" of the pyramids. A fatal defect in this telescope thesis, however, is the fact that the earth revolves, and a star visible for a few seconds at the aperture of the passage would be lost almost immediately from the field of vision.

In their astronomical observations and in their arithmetical calculations the Egyptians were inferior to the Chaldeans. They were familiar with the true meridian and the length of the sidereal year. They did not know the signs of the zodiac, however, nor are there any inscriptions of Egyptian origin such as are found on the Assyrian bricks, wherein appear the square and cubic multiplication tables and the three hundred and sixty degrees of the

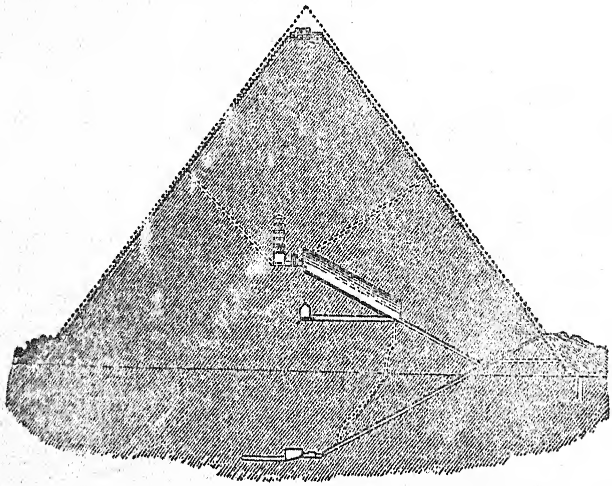


Fig. 1 —Great Pyramid, Showing 'Telescopic' Passages.

circle. The Egyptian "zodiac" of the temple at Derderah is now known to be a production comparatively modern in origin, even showing Greek influence.

The Hellenic philosophers made the first definite classification of elements, asserting that earth, air, fire and water were the four indivisible substances out of which the whole world was made up. They knew a god of the water, Poseidon (Neptune); a god of earth, Anteus; a

god of fire, Pluto, while each of the four winds was a deity. However simple and clear such a division might seem, modern science has proved that each of these supposed elements is divisible into several elementary substances. Thus ordinary water, for instance, is known to be compounded of oxygen and hydrogen; air is a mixture of nitrogen, oxygen, carbonic acid gas and a number of other elements more recently isolated, among which helium is of especial interest; and so numerous are the component parts of earth that it seems most strange how it ever could have been conceived as an element at all. Despite all errors in explaining the phenomena of nature, however, Greece must be credited with having made the first real beginning of that "classified knowledge" out of which has developed the natural science of modern times.

Thales, the founder of the Ionic school of philosophers, is reported to have determined the course of the sun from solstice to solstice and to have calculated eclipses. He attributed an eclipse of the moon to the interposition of the earth between the sun and moon, and an eclipse of the sun to the interposition of the moon between the sun and earth, and thus taught the rotundity of the earth, sun and moon. He also held that water is the principle of all things—a somewhat egregious error from the modern point of view. As early as two hundred and eighty years before the present era Aristarchus, Hippocrates and Galen made many scientific advances, but Physics was not yet strongly differentiated from its attendant sciences.

The mantle of the Greek philosophers was caught up by Pliny, who perished in the eruption of Vesuvius in 23 A.D. His Natural History in thirty-seven books treats of everything in the natural world—of the heavenly bodies, of the elements, of thunder and lightning, of the winds and seasons. Like nearly all the Greek and Roman philosophers, however, and many great theorists of later date, Pliny contented himself with theorizing.

In mathematics, metaphysics, literature and art the

Greeks displayed wonderful creative genius, but in natural science they achieved comparatively little. "It would not be correct to say that they possessed little or no aptitude for observing natural phenomena," says Florian Cajori in his 'History of Physics,' "but it is true that, as a rule, they were ignorant of the art of experimentation and that many of their physical speculations were vague, trifling and worthless. As compared with the vast amount of theoretical deduction about nature, the number of experiments known to have been performed by the Greeks is surprisingly small. Little or no attempt was made to verify speculation by experimental evidence. As a conspicuous example of misty philosophizing we give Aristotle's proof that the world is perfect: 'The bodies of which the world is composed are solids, and therefore have three dimensions. Now, three is the most perfect number —it is the first of numbers, for of one we do not speak as a number, of two we say both, but three is the first number of which we say all. Moreover, it has a beginning, a middle and an end.' "

Mechanical subjects are treated in the writings of Aristotle. The great peripatetic had grasped the notion of the parallelogram of forces for the special case of the rectangle. He attempted the theory of the lever, stating that a force at a greater distance from the fulcrum moves a weight more easily because it describes a greater circle.

Aristotle's views of falling bodies are very far from the truth. Nevertheless they demand attention, for the reason that, during the Middle Ages and Renaissance, his authority was so great that they play an important rôle in scientific thought. He says: "That body is heavier than another which, in an equal bulk, moves downward quicker." In another place he teaches that bodies fall quicker in exact proportion to their weight. No statement could be further from the truth.

A modern writer endeavors to exonerate Aristotle as a physicist. "If he could have had any modern instrument

of observation—such as the telescope or microscope, or even the thermometer or barometer—placed in his hands, how swiftly would he have used such an advantage!" But in the case of falling bodies, the experiment was within his reach. If it had only occurred to him, while walking up and down the paths near his school in Athens, to pick up two stones of unequal weight and drop them together, he could easily have seen that the one of, say, ten times the weight did not descend ten times faster.

Immeasurably superior to Aristotle as a student of

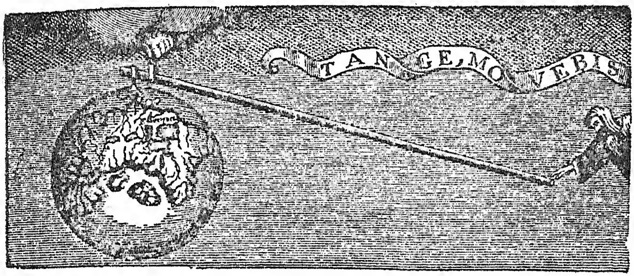


Fig. 2 —Archimedes and the Lever.

mechanics is Archimedes (287-212 B.C.). He is the true originator of mechanics as a science. To him belongs the honor of enunciating the theory of the center of gravity (centroid) and of the lever. In his 'Equiponderance of Planes' he starts with the axiom that equal weights acting at equal distances on opposite sides of a pivot are in equilibrium, and then endeavors to establish the principle that "in the lever unequal weights are in equilibrium only when they are inversely proportional to the arms from which they are suspended." His appreciation of its efficiency is echoed in the exclamation attributed to him: "Give me where I may stand and I will move the world."

While the "Equiponderance" treats of solids or the

equilibrium of solids, the book on "Floating Bodies" treats of hydrostatics. The attention of Archimedes was first drawn to the subject of specific gravity when King Hieron asked him to test whether a crown, professed by the maker to be pure gold, was not alloyed with silver. The story goes that the philosopher was in a bath when the true method of solution flashed on his mind. He immediately leapt from the bath and ran home, shouting, "I have found it!" To solve the problem, he took a piece of gold and a piece of silver, each weighing the same as the crown, the piece of silver being almost twice the size of the gold. He then determined the volume of water displaced by the gold, the silver and the crown respectively, and from that calculated the amount of gold and silver in the crown. The proportion of greater displacement in the crown above the piece of pure gold showed the extent of the alloy.

In his "Floating Bodies" Archimedes established the important principle, known by his name, that the loss of weight of a body submerged in water is equal to the weight of the water displaced and that a floating body displaces its own weight of water. Since the days of Archimedes able minds have drawn erroneous conclusions on liquid pressure. The expression "hydrostatic paradox" indicates the slippery nature of the subject. All the more must we admire the clearness of conception and almost perfect logical rigor which characterize the investigations of Archimedes.

Archimedes is said to have shown wonderful inventive genius in various mechanical inventions. It is reported that he astonished the court of Hieron by moving heavy ships by aid of a collection of pulleys. To him is ascribed the invention of war engines and the endless screw ("screw of Archimedes") which was used to drain the holds of ships. This genius, "the greatest scientist before Galileo," perished in the siege of Syracuse by the Romans (212 B.C.).

About a century after Archimedes there flourished

Ctesibius and his pupil Heron, both of Alexandria. They contributed little to the advancement of theoretical investigation, but displayed wonderful mechanical ingenuity. The force-pump is probably the invention of Ctesibius. The suction pump is older and was known in the time of Aristotle. According to Vitruvius, Ctesibius designed the ancient fire-engine, consisting of the combination of two force-pumps, spraying alternately. The machine had no air-chamber, and therefore could not produce a steady stream. Heron describes the fire-engine in his "Pneumatica." During the Middle Ages the fire-engine was unknown. It is said to have been first used in Augsburg in 1518.

Ctesibius is credited with the invention of the hydraulic organ, the water-clock and the catapult. Heron showed the earliest application of steam as a motive power in his toy, called the "eolipile." It was the forerunner of Barker's water-mill and the modern turbine. Heron wrote an important book on geodesy, called "Dioptra."

The Greeks invented the hydrometer, probably in the fourth century A.D. There appears to be no good evidence for attributing its origin to Archimedes. The hydrometer, a device in common use to-day for measuring the densities of water, milk and acids, is described in full by Bishop Synesius in a letter to Hypatia. It consisted of a hollow, graduated tin cylinder, weighted below. Immersed in a liquid, the depth to which it sank constituted a measure of the relative weight or density of that liquid. It was first used in medicine, to determine the quality of drinking-water, hard water being at that time considered unwholesome. According to Desaguliers, it was used for this purpose as late as the eighteenth century.

Since in such distant days, and with theories so diverse from those of modern times, the study of matter and of its properties began, the question arises whether the initial problem has yet been solved. Theories have been multiplied, modified, rejected, confirmed. Through centuries the

evidence of experiment has accumulated; much has been learned of the nature and behavior of matter under varying conditions, but the complexity of the problem has become more evident the further it is studied and the complete answer is not yet. The world is rife to-day with stores of knowledge undreamed of a few centuries ago, but since every addition to the sum of information brings with it a new series of problems, human reason halts before the attainment of a conclusive knowledge as to the real essence of that which it calls Matter.

The Greek-Roman Asclepiades conceived matter to consist of extremely small, but still divisible and fragile, formless and mutable collections of atoms, cognizable indeed by the understanding, but not by the senses. These atoms originally moved about uncontrolled in a general vacuum and burst in pieces through accidental collisions. By union of the finest fragments thus engendered, the "Leptomeres," originate the visible bodies, whose differences of form and varying peculiarities have their foundation in the different association of the leptomeres into different bodies.

In a quaint series of inquiries by John Abercrombie, 'The Investigation of Truth,' published in Edinburgh three-fourths of a century ago, Matter is defined as "a name which we apply to a certain combination of properties or to certain substances which are solid, extended and divisible and which are known to us only by these properties."

Francis Bacon, "the wisest, brightest, meanest of mankind," as Pope styled him, conceived of matter as made up of two "tribes of things," the "sulphureous" and "mercurial," which, he says, "seem vastly extensive, so as to enter and occupy the whole material world."

Sir Isaac Newton regarded matter as "the coexistence of the smallest particles which are themselves extended and material" and which, through a power whose nature he did not further analyse, hang together. Newton, therefore,

adhered to the atomistic school, of which the Greek Democritus of Abdera was the great classic expositor. He did not believe in the infinite sub-divisibility of matter.

In his "Treatise on Light" the great philosopher concludes that "it seems extremely probable that the Creator so formed Matter that its primary particles, out of which all possible bodies afterward arose, was firm, hard, impenetrable and movable." These particles therefore could not through any known force be divided, hence all bodies composed of these minute granules possessed interstices, because otherwise their parts could not be separated from one another, and matter was therefore divisible only until its atoms were reached. Moreover, these primary particles possessed not only a power which subjected them to certain immutable laws of motion, but also the capacity of being set in motion through other influencing causes, for example gravity, fermentation and cohesion.

In accordance with these premises, Newton justly combated the theory of his great contemporary, Cartesius, that matter occupied all space. His excellent development of the idea of the resistance of a medium led to conclusions which inevitably contradicted Cartesius' theory of filled space. In such a compact mass as the latter theory assumed, a mass which would be absolutely impenetrable, all motion must find an unlimited resistance. Cartesius assumed, it is true, that this subtle material was so finely divided as scarcely to exist at all, but Newton showed that this was only empty assertion. He based his opposition to the theory on the ground that the smallest subdividing of matter would not appreciably diminish the resistance which "filled space" would present to a moving body, especially since the body in motion would enforcedly have a density not greatly dissimilar to the resisting medium. Therefore, he argued, a medium wherein bodies move without perceptible retardation must be immensely more attenuated than the bodies themselves. On the other hand, a cannon-ball projected into the "filled space" of Cartesius,

be that medium ever so finely divided, would lose more than half its motion before it had moved a distance of thrice its diameter. It would be impossible on this supposition for a man to move from a given spot, much less the heavenly bodies, whose courses show no perceptible retardation, as would inevitably be the case were they to be advancing through an absolutely dense medium.

The belief in "filled space" did not originate with Cartesius. It is rather remarkable that the two thinkers who of all men in history most powerfully have swayed philosophic thought, Aristotle and Kant, were both exponents of the doctrine that space is continuously filled.

The great ancient expositor of the atomic theory was Democritus of Abdera. He taught that the world consists of empty space and an infinite number of indivisible, invisibly small atoms. Bodies appear and disappear only by the union and separation of atoms. Even the phenomena of sensation and thought he affirmed to be the result of their combination.

Newton's belief in the granular, or atomic, nature of matter has been abundantly upheld by the evidence of modern research. It is true that the chemical atom is no longer considered the ultimate unit of material structure. One brilliant writer on this subject has recently advanced a series of exhaustive arguments in favor of the Newtonian thesis. He points out, however, that it is by no means an impossible conclusion that matter in the form of interstellar ether may have properties quite different from those which are observed of matter in the mass.

It has been remarked above that Newton did not attempt to describe the nature of force; he merely assumed its existence as evidenced by the behavior of matter. This was natural, for reason must commence with an assumption and arrived at conclusions based simply upon the evidence of the physical senses. While force is generally conceived rather as an object of thought than of sense,

yet it should not be forgotten that force has just as real an existence as matter.

Many and various definitions of matter have been made in the course of scientific history. It has been described, for example, as "that which occupies space," or as "the receptacle of energy," or again as "the permanent possibility of sensation." All these may be brought under one of two general heads—either matter must be defined, as Bacon defined it, in terms of its properties, or it must be defined in terms of its coexistent phenomenon—force. It is clear that the physical world may be comprehended within the limits of these two notions—Force and Matter. Force is that which acts upon Matter, Matter is that by which man apprehends Force.

Force is by no means such a vague and various thing as is sometimes supposed. There is to-day a very general tendency among scientific writers to endeavor to reduce all force to a single underlying principle. The establishment of the theory of the Conservation of Energy; the ready transmutation in everyday experience of various forms of Force, such as the conversion of sound into electricity and of the latter into heat, light, motion or chemical energy; the advances in the study of radio-activity and the general acceptance of the kinetic theory of gases all point to an ultimate unification under some one great principle of the various forms of force.

Gravity alone seems incapable of classification with other forces, and this is due to its independence of any quality but mass. Temperature will affect the conductivity of an electric wire, solution is greatly influenced by pressure, light has a determinative effect upon physical life as upon many chemical reactions, but gravity is not affected by these conditions of temperature or of the intervening medium. Its nature is utterly unknown.

Electricity has long been held to be a form of force. It acts upon matter to change its condition; it is not an object of sense in a current-carrying wire or a charged Leyden

jar. It seems to be typical of what is popularly understood by the name force. Yet the study of the cathode rays by Sir William Crookes and his great co-workers in this field of research—Roentgen, Hertz, Rutherford and others whose names are perhaps even more familiar—has made it apparent that something closely resembling material particles are actually discharged from the cathode or negative pole of an electric conductor when the current passes. So strong indeed is the accepted belief that the nature of electricity is material rather than dynamic that Professor Remsen recently formulated the thesis that electricity is one of the elements.

To obtain a clear understanding of the most modern theories with regard to the nature of matter, a brief description of the apparatus used by investigators is indispensable. Imagine an electric bulb or oval vessel of glass. In this are placed two electrodes, which may be either metallic points or bulbs, or, in short, any poles separated by smaller or greater intervals and charged with electricity. Their electrification will be maintained, for example, by placing them in connection with the terminals of an electric current of high voltage. A short tube provided with a stop-cock allows the bulb to be exhausted of air. When the electric tension passes a certain limit a current is established.

If the vacuum is maintained at something less than a thousandth of an atmosphere this current appears as a soft rose-colored glow passing within the bulb from the positive to the negative pole. Sir William Crookes pushed the exhaustion of air in his experiments to a prodigious degree, the pressure being only one millionth of an atmosphere. Concerning Crookes' experiments, M. A. Dastre writes: "The English scientist claimed that when exhausted to this point the residue no longer has the properties of ordinary gases. According to him it is a hypergas as different from the true gaseous state as the latter is from the liquid state and forming a fourth condition of

matter, following the solid, the liquid and the gas proper; this he called radiant matter. Crookes desired to determine the nature of this fourth state of matter. In reality, the gas, rarefied to the millionth of an atmosphere, has not acquired, by this fact alone, an entirely new character; but it has acquired it most certainly when electrification is added to the rarefaction, and it is then that it constitutes the emanation or the cathode ray."

The vacuum must not be pushed too far; if one goes beyond the millionth of an atmosphere—and the perfection of mechanism allows going much further than that—the gaseous residue cannot be electrified; electricity will not

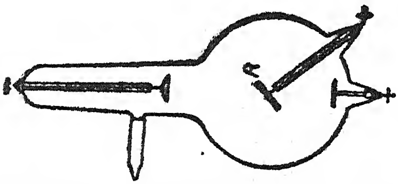


Fig. 3 —A Common Form of X-ray Tube.

pass through; there is no longer a current. The electric force is incapable of penetrating absolute vacuum. The importance of this principle is very great from the theoretical point of view; it furnishes, in fact, a new test for matter.

But in Crookes' tube, in which the vacuum has been pushed to one millionth, the current behaves itself rather differently from what it does in the tubes where the rarefaction is less. The path of the current has lost much of its brilliancy; it no longer appears as an uncertain glow, wavering, striated, of a hue intermediate between rose and violet. All the remainder of the interior of the bulb now remains dark. The electricity passes as before between the positive electrode and the cathode or negative pole. The principal flow has been joined by a secondary one; from

all points of the tube the positive currents are directed toward the cathode and go to reinforce the principal current. These positive charges which descend from all points of the exterior form the counterpart of the negative charges, which can be seen fixed on the cathode rays. Their existence, their development, their circulation result in consequence from the existence, the development and the inverse circulation of the negative electricity that carries with it the cathode ray.

Such is the cathode afflux; it is composed of the current directed toward the positive electrode and of secondary currents directed from all parts of the recipient toward the cathode. This cathode afflux has, besides, the character and the properties that physicists and chemists attribute to the electric current. It touches directly the cathode.

The afflux, however, is in fact perfectly distinct in every respect from the cathode radiation which follows it. The latter is formed of a pencil of rays perpendicular to the surface of the cathode. It traverses the tube in a perfectly straight line without being disturbed by the rays flowing toward the cathode in an opposite direction, of which we have just been speaking; it passes by them and through them unchecked.

This new pencil implanted perpendicularly on the cathode is not luminous. It is not directly visible; it forms a dark spot in the Crookes tube. It would entirely escape observation if it did not excite a peculiar fluorescence opposite to the cathode at the points where it meets the sides of the tube. The material of the glass becomes illuminated at these points and presents a luminous brilliant spot of a green color.

Crookes conceived the idea of arranging in the interior of the tube, in the path of the pencil of rays between the cathode and the wall, a cross of aluminum. He then saw outlined against the clear fluorescent background the exact silhouette of the cross.

If the cathode is a mirror with spherical concave surface

the perpendicular lines at the surface form a conic pencil and converge toward a focus. The effects peculiar to cathode rays are magnified by this concentration, in the same manner that the effects of luminous rays are increased in the focus of a lens. In this manner Crookes was able to show the heating action of his supposed radiant matter; that is to say, of cathode rays. He succeeded in

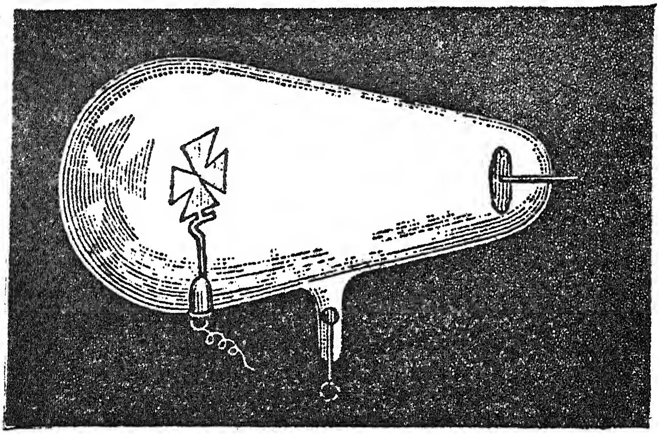


Fig. 4 —Cathode Radiation.

fusing, at one of these foci, not only glass but a wire of iridium-platinum, an operation which requires a temperature of more than 2,000°.

When the cathode rays are reflected from a sheet of platinum within the tube the marvelous phenomena of X rays, or Roentgen rays, are produced. These rays are different in character from the cathode rays in that they pass readily through wood, flesh, cardboard and even thin sheets of metal. Their serviceability in locating and determining the nature of a fracture in a bone is too well known to need comment.

The cathode projectile does not depend upon the nature of the cathode. It has been proved to be composed of hydrogen. It has its origin necessarily in the breaking up of an atom of hydrogen. (Villard showed that the cathode rays exhibit the spectrum of hydrogen, and if every trace of this gas is removed the cathode emission is suddenly suppressed.)

"Hydrogen," observes M. Dastre in the article quoted above, "instead of being the final expression of simplicity and of lightness, as chemists believe, appears to be a quite complex edifice and rather heavy, since the current of the Crookes tube removes from the stones which represent it but the thousandth part of its mass. These stones are the fragments of atoms, or the atomic corpuscles of J. J. Thompson. The atom is no longer indivisible."

The infinitesimal mass of an atom is a fact sometimes lost sight of in discussing the constitution of matter. It has been estimated from experimentation with colored solutions of a known concentration that the weight of an atom of hydrogen is less than 0.0000000000019008 oz. and its diameter is less than 0.000000002 in.

Following this line of inquiry as to the ultimate constitution of matter, there has recently appeared an article by Dr. W. D. Horne which reads in part as follows:

"From considerations based (partly) on very elaborate mathematical calculations it is now maintained that matter is composed of electricity and nothing else. Electricity here is not considered as a form of energy any more than water is a form of energy, but as a vehicle of energy, which can be moved from place to place and whose energy must be in the form of motion or of strain. In motion it constitutes current and magnetism; under strain it constitutes charge, and in vibration it constitutes light."

Continuing, the same writer says: "Sir Oliver Lodge describes the atom of matter as constituted of an individualized mass of positive electricity diffused uniformly over a space the size of an atom, perhaps spherical in

shape and about one two hundred millionth of an inch in diameter. Throughout this small spherical space some eight hundred minute particles of negative electricity, all exactly alike, are supposed to be scattered, flying vigorously about, each repelling every other and yet all contained within their orbits by the mass of positive electricity. The positive electricity is very much attenuated and constitutes perhaps only about one per cent of the mass of the atom, while the negative electrons are correspondingly dense and so inconceivably small that the eight hundred are less crowded in their atom than are the planets in the solar system. Atoms of different kinds of matter are supposed to be constructed in the same general manner and of the same kind of electrons, but the number of electrons in an atom are proportional to the atomic weight of the element. Thus oxygen would have sixteen times as many electrons in its atom as has hydrogen. When the crowding becomes excessive, as in the very heavy atoms of uranium (the heaviest substance known), thorium and radium, having atomic weights well over two hundred, the atoms become radio-active, probably due to numerous collisions between the electrons, some of which are being constantly shot away."

This perspicuous summary of the so-called electron theory is highly suggestive of the fundamental unity of force and matter. Moreover, the electron theory seems, so far, most in accord with the results of recent investigation into the physical basis of the material universe.

Curiously enough, the medieval alchemists who, next after the Greeks, attempted to establish an orderly classification of the elements, actually anticipated one of the most modern theories regarding the properties of matter. They believed in the Philosopher's Stone, which, if it could but be discovered, would make possible the transformation of any or all of the baser metals into gold. Recent investigation has shown that something like a true Philosopher's Stone actually exists and is known in the world to-day. It

is a well accepted belief that the earth in its passage through space gathers up constantly minute quantities of the gas helium, so called because its spectrum was found first in the analysis of light from the sun and before the discovery of the element in the terrestrial atmosphere. The theory has lately been advanced that under the influence of helium the nobler metals, silver and gold, are slowly disintegrating and their electrons recombining through immense periods of time to form the baser metals, iron, copper, tin, zinc, etc.

In a discussion of modern views on matter, Sir Oliver Lodge observed that the facts recorded in connection with the study of radio-activity constituted a phenomenon quite new in the history of the world. "No one," he says, "hitherto has observed the transition from one form of matter to another, tho throughout the Middle Ages such a transmutation was looked for. The evolution of matter likewise has been suspected by a few chemists of genius. It was perceived, on the strength of Mendeleeff's law (the periodic law), that the elements form a kind of family or related series, and it was surmised that possibly the barriers between one species and the next were not absolutely infrangible, but that temporary transitional forms might occur. All this was speculation, but here in radio-active matter the process appears to be going on before our eyes."

CHAPTER II

THE PROPERTIES OF MATTER

THE foregoing brief inquiry into the essence of matter leads naturally to a consideration of its properties. Of these properties the first and foremost is that of weight. The term "ponderable matter" has long been used to distinguish matter in the mass, whereby is plainly indicated the most fundamental property of matter as such. Even in ancient times it was realized that any consideration of matter would deal primarily with questions bearing a definite relation to weight, and the development of the knowledge of the laws concerning the attraction of bodies for each other is closely allied to the inner history of Physics.

In that renascence of learning and thought which succeeded the gloom of the Dark Ages in Europe arose many great lights of science. Copernicus outlined the system which subsequently became known by his name. Kepler grappled with the problem of determining the paths of the planets. Galileo laid the foundation of experimental science. The belief in the earth as the center of the universe was then overthrown. Copernicus taught that the earth was not flat, but spherical; that it rotated on its axis and revolved around the sun; that seasons are due to the inclination of the earth's axis. He defined gravity as "nothing other than a certain natural appetite innate in the parts of matter by the divine providence of the Artificer of the universe, so that they assemble themselves in an exact unity, combining in the form of globes." The marvelous

mathematical insight of Kepler proved the accuracy of the Copernican theory, and he demonstrated that the elliptical orbit of Mars would accord exactly with this theory and with no other.

The famous experiments of Galileo with falling bodies constituted as clear a proof of a principle as ever man has made. The young investigator was the first actually to try out the assertion of Aristotle that falling bodies would descend with a velocity proportionate to their weight—a stone weighing ten pounds would fall ten times as fast as a stone weighing but one pound. Galileo did not believe this, and having found from experimentation that it was not so, openly proclaimed his conviction that Aristotle was wrong. His opinions were hotly opposed by the learned professors of the University of Pisa. By agreement the case was put to the test, and from the top of the leaning tower of Pisa Galileo allowed a small cannon ball and a large bomb to drop together. "The multitude saw the balls start together, fall together and heard them strike the ground together. Some were convinced, others returned to their rooms, consulted Aristotle, and, distrusting the evidence of their senses, declared continued allegiance to his doctrine."

Galileo then experimented with a polished brass ball rolling down a smooth incline, in order to establish the ratio between the distance traversed and the time of falling. Clocks did not exist in his day, and he resorted to a very interesting and ingenious device for measuring the time elapsing during the progress of this experiment. Attaching a small spigot to the bottom of a water pail, he caught the escaping water and measured its weight, comparing the increase of weight with the distance traversed by the ball. From these experiments he found the distance to increase very closely as the square of the time.

Galileo's reflections had brought him to the confident belief that Copernicus' theory of the solar system was as true as that of Aristotle was false. He taught and wrote

much in support of this doctrine and by his sarcastic raillery against the narrow prejudice of his contemporaries incurred the enmity of many. As an old man of nearly seventy he published a brilliant defence of the Copernican system which aroused such fierce antagonism that he was forced publicly to abjure and to curse his "detestable heresy"—viz., that the earth moves round the sun. His "E pur si muove" (But it does move!), uttered as he came forth from his trial, has become historic.

The extraordinarily active mind of this investigator seemed ever to be discovering new and interesting phenomena. It is said of Galileo that while he was praying in the cathedral at Pisa his attention was drawn to the lamps which had been lighted and left irregularly swinging above the altar. His mind at once set off on the question as to whether the period of a pendulum would vary exactly with the amplitude (width) of its vibration. He timed one of the swinging lamps by his pulse and found that the period of vibration was exactly the same, no matter whether the pendulum was swinging violently or dying down to rest.

Later experiments confirmed this conclusion and led likewise to the discovery that the length only of a pendulum affected the time of its oscillation. A slender wire, with a small steel ball for a bob, swings to and fro in exactly the same period as a heavy iron bar whose center of gravity is at an equal distance from the point of suspension. Galileo found out that the swing of a pendulum varied as the square root of its length. Thus a pendulum four feet long will vibrate half as fast as a pendulum a foot long.

The pendulum is used to-day in experimenting upon the attraction due to gravity in different parts of the earth, and by its help the flattening toward the poles of the curved surface of the earth can be exactly determined. The attraction due to gravity varies inversely as the square of the distance from the center of the earth. Thus a pendulum which possesses at New York a length of 39.1

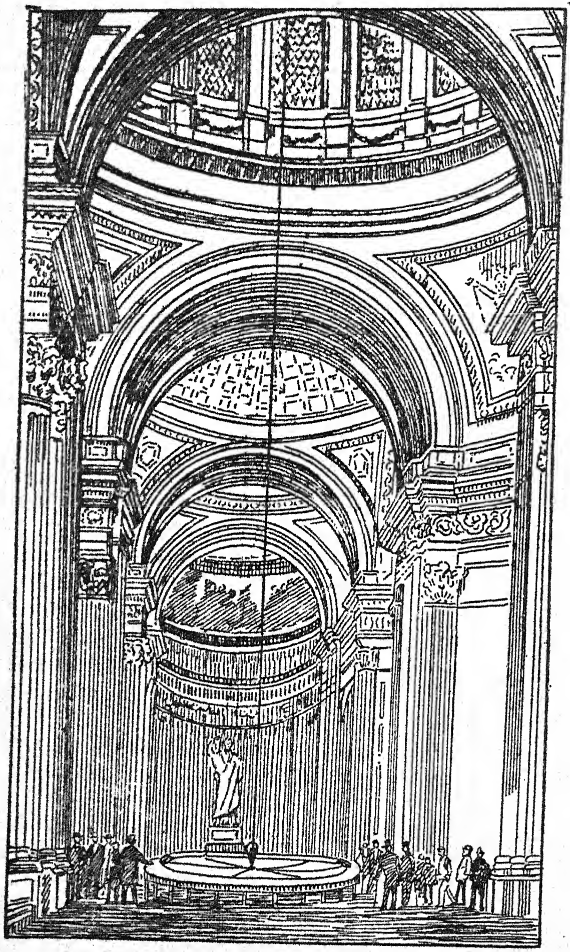


Fig. 5 —Foucault's Experiment Showing Rotation of the Earth.

inches will vibrate once every second at that point of the earth's surface. As it moves toward the poles the pendulum vibrates more rapidly. If the change of location is made in the direction of the equator the vibration is slower; this for the reason that the pull of the earth is less, since at the equator the pendulum is farther from the center of gravity of the earth.

Of the same character was the famous Foucault experiment to show the rotation of the earth. On this experiment it was shown that a pendulum at rest, if of sufficient length, would oscillate owing to the motion of the earth, the various factors operating throughout the pendulum, each point of which was at a varying distance from the center of the earth.

The discovery that a pendulum of fixed length always vibrated in the same period led naturally to the invention of the pendulum clock. For this invention credit has been ascribed to several unknown men, but it is probable that the honor should be divided between Galileo and his famous Dutch contemporary, Christian Huygens. The significance of this invention in the history of physical science is great indeed, when account is taken of the innumerable forms of experimentation which have been reduced by its aid to exact sciences.

While Galileo, Kepler and Copernicus had completely overthrown the ancient theory of Aristotle that the earth is the center of the universe, and had mathematically proved that the solar system revolves about the sun as a center, they did not show the "why" of these new and startling discoveries. The puzzle stared philosophers in the face, What is it that causes the planets to move in their orbits? To this question Descartes proposed the novel and striking explanation of a series of whirls or vortices. All space, he argued, was filled with a fluid, the parts of which, acting on each other, caused circular motion. Thus the fluid was formed into a multitude of vortices of various density and size. A huge vortex round

the sun carries with it the earth and all the other planets. Each planet in the same way is the center of a vortex of its own and draws bodies to itself in much the same way that a log of wood is drawn into the center of a whirlpool. Cohesion between the different parts of a body he explained in the same manner as the result of infinitesimally small vortices.

Unsatisfactory as this vortex theory seemed and quite out of accord with the laws which Kepler's intellect had formulated, yet the weight of authority lent to it by the great name of Descartes resulted in its persistence as a generally accepted theory until the middle of the eighteenth century.

Greatest of all natural scientists of this or any time and first to formulate completely and finally the laws of matter was the great English mathematician and physicist, "prince of philosophers," Sir Isaac Newton. It was reserved for his genius to show why the apple which falls from a tree falls down to the earth and not up to the clouds; how the earth, this infinitesimal point in space, does not rush headlong into the sun or fly off at a tangent into the void beyond the solar system; why the wave rebounds from the cliff and why the pendulum swings to and fro. Newton's Law of Universal Gravitation is the catechism of astronomy; his Three Laws of Motion have become the basis of physics and the bed-rock of the science of mechanics. That which is known as Newton's Law of Universal Gravitation is in brief as follows:

Any two bodies in the universe attract each other with a force which is directly proportional to the product of the masses and inversely proportional to the square of the distance between them.

The term mass, as used here and generally in a physical discussion, refers to a constant quality of weight in a body. As a pendulum varies in its swing at different points upon the earth's surface, so a pound of iron at the equator will weigh less than a pound in Greenland. The

influence of the earth acts upon all bodies exactly as tho its whole mass were concentrated at the center. Hence a pound weight at the surface of the earth, 4,000 miles from its center, would weigh, according to Newton's law of gravitation, heavier and heavier as it approached the center. Similarly if the weight were carried away to a distance of say 4,000 miles from the surface of the earth, it would weigh only one-fourth as much as it did at the surface, since it is twice as far away from the earth's center. Or again, a body which would weigh 1,000 ounces at sea level would weigh about 998 ounces at the top of a mountain four miles high. Nevertheless the mass of the body—*i.e.*, its power to attract other bodies—would remain the same.

An athlete who weighs 150 pounds can leap at the surface of the earth over a bar six feet high. Carry him to the moon and the same muscular effort would carry him at a bound over an obstacle forty feet high and his descent on the other side would be comparatively slow. The mass of the moon being about one-seventh that of the earth, the same effort would accomplish seven times as much work, since the resistance to be overcome would be the mass of the man multiplied by the mass of the moon.

If it is true that the earth attracts the moon, it is equally true that the moon attracts the earth, as is shown by the tidal wave which follows the moon in its apparent revolution around the earth, and this attraction is equal to the product of the masses of the moon and the earth. Were the moon brought to a point one-fourth as distant as its present path around the earth, its speed of revolution would be enormously increased and its influence on the water surface of the earth would raise resistless mountain tides, sweeping the land from east to west as the earth revolved. Newton's famous apple, detached from the tree, leaps to meet the earth; but it is equally true that the earth leaps up to meet the apple. The relatively great disturb-

ance in the position of the apple is due only to the vastly greater mass of the earth.

Newton's great Laws of Motion were stated thus:

(1) Every body continues in its state of rest or uniform motion in a straight line unless impelled by external force to change that state.

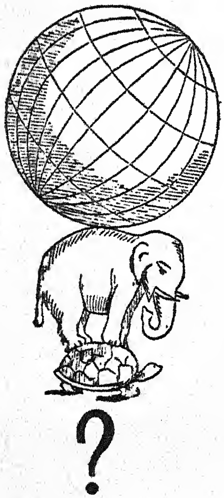
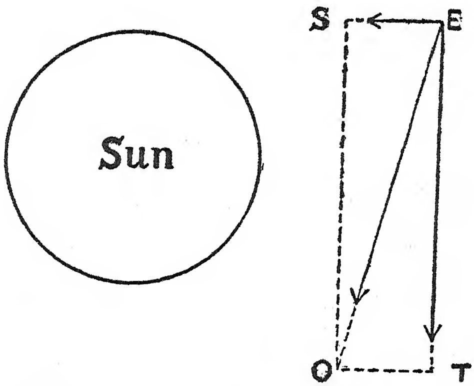


Fig. 5 —GRAVITATION DRAWING, ASCRIBED TO THE PEN OF SIR ISAAC NEWTON.

Standing on a moving car, the passenger is thrown violently forward when the car comes to a sudden stop and backward when the car starts; he tends in each case to continue in the previous state, whether that were one of rest or motion. Water flies from a whirling grindstone, mud from the spinning wheels of a rapidly driven motor car. At each instant the world is rushing forward in a straight line through space, but at the same instant the prodigious mass of the sun is acting upon it to pull the earth into itself. Between these two forces the earth is impelled in an almost circular orbit around the sun—the centrifugal

force is exactly balanced by the centripetal force which acts upon the earth exactly as two bits of floating wood in a quiet pond will come together or as a vessel drifts to meet an iceberg. The resultant of the two forces acting upon the earth may be apparent from the following diagram:



Suppose the short side of the oblong, ES, represents the direction and extent of the sun's attraction for the earth; then if ET, the long side, represents the tendency to fly off at a tangent, the resultant motion will evidently be between these two. Aristotle knew that if two such forces were acting at right angles on a body the resultant motion would be represented by the diagonal of a rectangle of which the forces were sides. The line EO, representing a part of the earth's path around the sun, appears as a straight line only because it is taken as a very small arc of an enormous circumference.

(2) Rate of change of momentum is proportional to the force acting and takes place in the direction in which the force acts.

On a steep slope gravity impels a body more than on a gentle incline. A sled will gather headway faster on an

ance in the position of the apple is due only to the vastly greater mass of the earth.

Newton's great Laws of Motion were stated thus:

(1) Every body continues in its state of rest or uniform motion in a straight line unless impelled by external force to change that state.

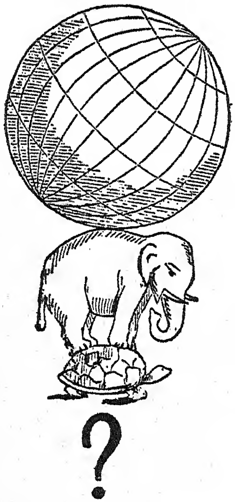
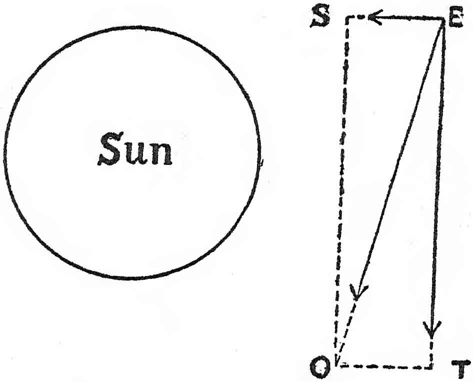


Fig. 6 —Gravitation Drawing, Ascribed to the Pen of Sir Isaac Newton.

Standing on a moving car, the passenger is thrown violently forward when the car comes to a sudden stop and backward when the car starts; he tends in each case to continue in the previous state, whether that were one of rest or motion. Water flies from a whirling grindstone, mud from the spinning wheels of a rapidly driven motor car. At each instant the world is rushing forward in a straight line through space, but at the same instant the prodigious mass of the sun is acting upon it to pull the earth into itself. Between these two forces the earth is impelled in an almost circular orbit around the sun—the centrifugal

force is exactly balanced by the centripetal force which acts upon the earth exactly as two bits of floating wood in a quiet pond will come together or as a vessel drifts to meet an iceberg. The resultant of the two forces acting upon the earth may be apparent from the following diagram:



Suppose the short side of the oblong, ES, represents the direction and extent of the sun's attraction for the earth; then if ET, the long side, represents the tendency to fly off at a tangent, the resultant motion will evidently be between these two. Aristotle knew that if two such forces were acting at right angles on a body the resultant motion would be represented by the diagonal of a rectangle of which the forces were sides. The line EO, representing a part of the earth's path around the sun, appears as a straight line only because it is taken as a very small arc of an enormous circumference.

(2) Rate of change of momentum is proportional to the force acting and takes place in the direction in which the force acts.

On a steep slope gravity impels a body more than on a gentle incline. A sled will gather headway faster on an

abrupt descent. A car will gain speed faster with a greater current through the motor. Other things being equal, a steamer with two propellers making 500 revolutions per minute would travel twice as fast as the same steamer under one propeller. Here, however, the resistance of the water at the bows (which increases for high speeds very nearly as the cube of the speed) and the whirl of water astern, which reduces the perfect efficiency of the screw, would have to be taken account of.

(3) Newton stated his third law thus: To every action there is an equal and opposite reaction.

This does not mean that a bouncing ball will go on bouncing forever. Every one knows that it will not. It does not mean that the "kick" of a gun is exactly equal to the force with which a bullet leaves the muzzle or that a pendulum will swing up on one side exactly as far as it swung down on the other. In all these cases the energy expended is equal to the work accomplished, but in each case part of the energy is expended in overcoming resistance and doing work which cannot be seen. A tennis ball dropped to the floor will rebound about three-fourths as high as the point from which it fell. Part of the energy of compression was expended in the flattening of the cover of the ball and part in overcoming the resistance of the air. The kick of the gun is taken up by a padding of clothes; the pendulum is retarded by friction.

The most elastic solid in the world is steel. To the majority of people it would appear that some such resilient material as rubber or ivory is the most elastic. This is not the case. Within a low range of strains it is true that rubber has very great elasticity; the tendency of its molecules to resume their former positions after being distended is very great. Beyond the limit of this tension, however, the rubber stiffens, the molecules fall asunder and the band breaks. A steel piano wire, on the other hand, will carry strains varying from one or two pounds to many hundreds of pounds, will stretch regularly under the tension and

will always resume its original length. Many hundreds of stretchings will not measurably increase the length of the wire. If the elastic limit is reached, however, the molecules will not resume quite their former positions. As before observed, the elastic limits for steel are very wide indeed.

A plastic substance such as lead, on the other hand, possesses almost no elasticity. Its reaction to molecular displacement appears in the form of heat generated among the molecules. A very little hammering will soon make a piece of lead too hot to touch, while the same work done upon a piece of iron of the same weight does not appreciably warm it, for the reaction comes mainly in the rebound of the hammer from the iron. Steel is more elastic than iron and iron more than any other metal.

The extreme elasticity of steel may be gathered from the results of experimental evidence, whereby it has been shown that a drawn steel wire one millimeter ($\frac{1}{25}$ inch) in diameter returns completely to its original length so long as the stretching force is less than 32 kilograms (70 pounds). Within this limit, therefore, steel is said to possess perfect elasticity. A drawn copper wire of the same diameter shows perfect elasticity only until the stretching force has reached 12 kilograms (about 26½ pounds).

Robert Hooke, a contemporary and friend of Newton, formulated about the end of the seventeenth century what is known as Hooke's Law, which states:

"Within the limits of perfect elasticity elastic deformations of any sort, be they twists or bends or stretches, are directly proportional to the forces producing them."

This means simply that a rubber ball, a steel ball, an ivory ball or almost any sort of solid body will, if compressed, resume its former shape as soon as the pressure is removed, provided that the compression has not been too great. The greater the strain necessary to produce a small deformation, the greater is said to be the elasticity

of the body. Gases alone possess perfect elasticity for all degrees of pressure. All gases under pressure tend to expand indefinitely upon the release of the pressure. By sufficient pressure and extreme cold all gases may be so far reduced in volume that they become liquid. The liquefaction of gases was first successfully accomplished by Michael Faraday about 1823. Other experimenters followed, but no great advance in this direction was made until 1877, when Cailletet and Pictet, working independently, succeeded in liquefying oxygen. Their process consisted in compressing the gas into a small tube, cooling it and then suddenly allowing it to expand by removal of the pressure. The principle is essentially the same as that in use to-day, and there exists no gas which has not been examined in the liquid state. Most gases as such are colorless; oxygen gas has no color, but liquid oxygen is milky white; hydrogen gas as such is colorless, but liquid hydrogen is steel blue.

As before observed, sufficient pressure will reduce most gases to the liquid state. It is a remarkable fact, however, that a temperature has been determined for every common gas above which no amount of pressure, however great, will succeed in making it liquid. This critical temperature varies for different gases. Liquid air cannot be produced at a temperature higher than 220° (Fahrenheit) below zero. Hydrogen must be cooled to a temperature of more than 400° below zero before it can be liquefied. The terms "frigid" and "icy" are hopelessly inapplicable to these terrific degrees of cold, for ordinary ice, as is well known, is so warm that a vessel of liquid air placed upon a block of ice will boil violently, while the temperature of liquid hydrogen is nearly as far below that of liquid air as the latter is below the freezing point of water.

It might be interesting to note, in passing, that hydrogen, which for a long time resisted all efforts at liquefaction, was finally produced by James Dewar in 1902, not merely as a liquid but as a solid. This he accomplished by

expanding liquid hydrogen into a space continually exhausted by an air pump, reaching thereby the incredibly low temperature of 430.6° Fahr. below zero. The record of extreme cold has been carried even farther back than this. In July, 1909, Prof. H. Kamerling Omnes, of Leyden, by evaporating liquid helium into an exhausted tube obtained a temperature which nearly reached 3° 'absolute.' This would equal 270° Centigrade, or 454° Fahrenheit, below zero.

Galileo had proved that air has weight by weighing a glass globe, forcing more air into it and weighing it again. The increase of weight he rightly attributed to the added air. It did not occur to him, however, that the weight of air had anything to do with nature's horror of a vacuum. He was amazed when informed that a lift pump had been constructed with a tube about forty feet long and that no amount of pumping would cause the water to rise higher than about thirty-three feet. He observed that Nature's horror of a vacuum was an instinct which she did not always display. Above the water was a vacuum, but the water refused to fill it. So, said he, Nature's dislike of a vacuum might be measured by the height of the column of water which it would support.

Galileo's friend and pupil, Torricelli, musing over this suggestion, came to the conclusion that the weight of the water in the suction pipe was supported by the weight of air upon the cistern outside. Torricelli knew that mercury was about thirteen times as heavy as water; he reasoned that the air ought to support a column of mercury one-thirteenth as high as the column of water in the suction pump. He had a glass tube made about 33 inches long, closed at one end and completely filled with mercury. Closing the open end of the tube with his finger, he inverted it in a dish of mercury. The mercury sank a little way in the tube and came to rest with its surface 30 inches above the free surface of the mercury in the vessel below. Torricelli had constructed the first barometer.

The name of Pascal is indissolubly associated with the hydraulic press. He was interested, however, in Torricelli's novel experiment and, having tried it, concluded that "the vacuum is not impossible in Nature and she does not shun it with so great horror as many imagine." Pascal reasoned that if one were to ascend a mountain, the pressure of the air at the greater elevation should be less, because there would be less air overlying the mountain top than there was overlying an equal area of the plain. Accordingly he wrote to his brother-in-law, who lived near the Puy de Dome, an ancient volcano in the Auvergne, France, asking him to ascend the mountain with a Torricellian tube and observe whether the mercury column would not fall because of the diminished atmospheric pressure. The experiment was made and it was found that the mercury column became three inches shorter during the ascent, but gradually resumed its previous length during the descent to the plain.

Pascal also repeated Torricelli's experiment with wine instead of mercury, and he found, as he had inferred, that, since wine is less dense than water, the atmosphere balanced a column of it which was longer than the water column, for of course it would take a longer column of the lighter fluid to make the same weight.

The hypothesis of Torricelli and Pascal as to the pressure of the atmosphere was thus placed upon a firm experimental basis and was now competent to explain the phenomena of pumps, but it required the evidence of many more experiments to secure its general acceptance.

The most remarkable man of this period, however, in view of the multitude and the ingenuity of his experiments, was Otto von Guericke, who later became mayor of the city of Magdeburg. The Magdeburg Hemispheres have become a familiar word owing to his famous experiment made in 1654 at Regensburg before the Reichstag and the German Emperor, Ferdinand III. Two hollow hemispheres of steel, about 1.2 feet in diameter, were cast for his re-

markable experiment. They were fitted at either end with heavy iron rings and provided with a tube and stop cock. The edges were made broad, smoothed and polished to a perfect plane so that they might fit exactly together. Then the air was pumped out of the interior, the stop cock turned off and twelve horses, six at each end, were hitched to the rings in the hemispheres. Their combined efforts failed to overcome the pressure on the outside of the spheres. Another team of horses was attached, and yet another, and the spheres were finally pulled apart.

A simple calculation will show that this result was inevitable, the average horse, it is estimated, being able to exert a pull equal to about 600 or 650 pounds horizontally. According to the known formula for the surface of a sphere of 1.2 feet diameter, these hemispheres would have about 652 square inches area. Reckoning the atmospheric pressure upon the outside of the two hemispheres at 15 pounds to the square inch, and assuming that the internal pressure has been reduced to a negligible quantity, it is apparent that the pressure to be overcome would equal, roughly, 9,780 pounds. According to von Guericke's calculations, a force of 2,686 pounds would overcome the atmospheric pressure upon the exterior of the spheres. Here must be some error!

There is extant a quaint old engraving showing the horses endeavoring to separate the exhausted hemispheres. On the occasion of this experiment von Guericke asserted that if you were to blow your breath into a large exhausted receiver, you would that moment breathe your last. The truth of this being doubted, he illustrated the power of "suction" by a new experiment. "A cylinder of a large pump had a rope attached to its piston, which led over a pulley and was divided into branches on which twenty or thirty men could pull. As soon as the cylinder was connected with an exhausted receiver the piston was suddenly pushed down by the atmospheric pressure and the men at the ropes were thrown forward."

The air pump used by the distinguished mayor of Magdeburg was his own invention. The upper bulb was of glass. A glance will show that the instrument was but a clumsy affair compared with those in use to-day. A better

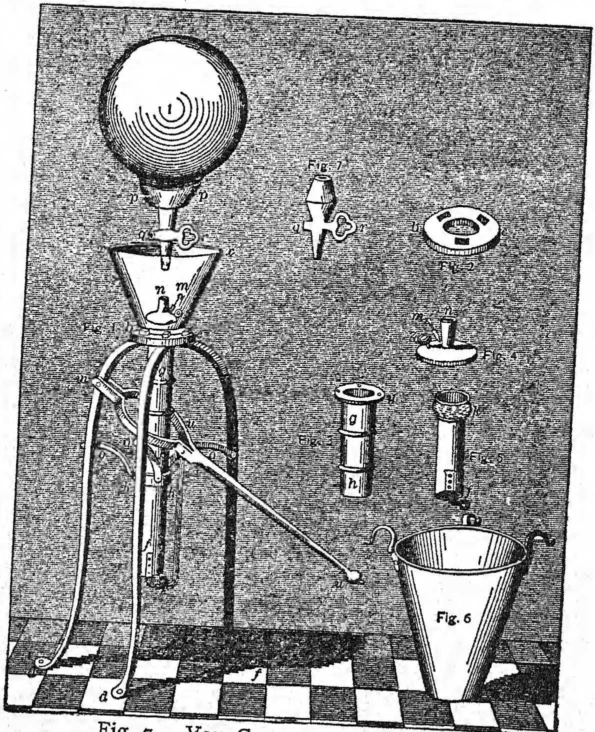


Fig. 7 —Von Guericke's Air Pump.

pump was made by Boyle and Hooke in England some six years later.

It was not long after these remarkable experiments of von Guericke that Robert Boyle published his "New Ex-

periments Touching the Spring of the Air" and stated the law which has since borne his name:

Under like conditions of temperature and pressure the volume of a gas varies inversely as the pressure upon it.

"We took then a long glass tube," he writes, "which by a dexterous hand and the help of a lamp was in such a manner crooked at the bottom that the part turned up was almost parallel to the rest of the tube and, the orifice of this shorter leg being hermetically sealed, the length of it was divided into inches (each of which was divided into eight parts) by a straight list of paper, which containing those divisions, was carefully pasted all along it. (A similar strip of paper was pasted on the longer leg.) Then as much quicksilver as served to fill the arch or bended part of the siphon was poured in so as to be at the same height in both legs. This done, we began pouring quicksilver into the longer leg till the air in the shorter leg was by condensation reduced to take up but half the space it possessed. We cast our eyes upon the longer leg of the glass and we observed, not without delight and satisfaction, that the quicksilver in that longer part of the tube was 29 inches higher than the other."

Experimentation in measuring the weight of the air was naturally followed by efforts at more exact estimations of temperature. The air thermometer of Galileo was an exquisitely sensitive instrument, but having an exposed liquid surface was subject to barometric influences as well as those of heat and cold. Fahrenheit, toward the end of this century, devised the thermometer which bears his name. He selected his zero at the lowest temperature which he knew how to obtain and took the highest fixed point at the temperature of the human body. He divided this space into twenty-four equal parts and then, finding these degrees too large, subdivided each into four parts, thus making the temperature of the body 96°. On this basis of division the freezing point of water happened to come at 32° and the boiling point of water at 212°. And there

they stay to this day, despite the fact that all modern physicists measure temperature on the excellent Centigrade scale of Celsius, whereon the freezing point of water is zero and the boiling point 100°.

Nearly a century after the invention of Fahrenheit's thermometer and fifty years later than that of the Swedish astronomer Celsius, need was found for a third type of thermometer. The experiments of Charles, Dalton, Gay-Lussac and others had determined the fact that for every degree Centigrade of increase in temperature above zero the volume of a gas increased by $\frac{1}{273}$ of itself. Similarly a decrease of 1° below zero meant a decrease of $\frac{1}{273}$ in volume of the gas. A decrease of 2° meant a reduction in volume of $\frac{2}{273}$. Hence a fall of 273° would mean a reduction of $\frac{273}{273}$, or, in other words, the volume of the gas would be reduced to zero. This was absurd, for the law of the indestructibility of matter would not allow that something could become nothing. The explanation, however, soon was found in the fact that all gases become liquid before reaching this point, and it is a matter of common knowledge that liquids are practically non-compressible. The temperature of 273° Centigrade then was taken as the zero of the absolute scale, because it was believed (and there is yet no evidence to disprove it) that at that temperature the molecular motions of all bodies would entirely cease, the molecules would be perfectly at rest.

With this thermometer in mind, the statement of the law of gases, called Charles' Law, or Gay-Lussac's Law, is simple. It was:

The volume of a gas varies directly as the absolute temperature.

Brief mention herein has been made of the remarkable experiments of William Crookes upon the so-called cathode rays in the highly exhausted tubes which have since borne his name. In the course of his investigations upon the properties of the newly discovered element, thallium, he attempted to carry out the necessary delicate weighings

in a vacuum, in order to avoid the effect of the buoyancy of the air. Irregularities in the weighings which he was quite unable to explain led him to the invention of his famous radiometer, an instrument now common enough in the windows of opticians' stores.

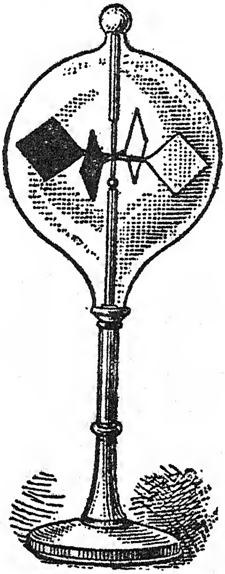


Fig. 8 —Crookes' Radiometer.

It consists of a delicate paddle wheel with four metallic vanes, polished on one side and blackened on the other, mounted so as to revolve in a partially exhausted tube. Light falling upon the dark surfaces is absorbed, and the temperature of the residual gas next these surfaces is therefore raised in accordance with the well-known fact that "black is a warmer color than white." Higher temperature means greater molecular activity (as will appear

in the chapter on Heat). Hence the vanes are pushed backward into the region of comparative quiet on the polished side. When light is withdrawn the revolution ceases and the brighter the light the faster the revolution. At first Crookes believed the rotation of the vanes to be due to ether waves, but by exhausting the bulb to an extremely high vacuum he found the wheels did not revolve. He therefore fell back upon the modern Kinetic Theory of Gases, attributing the motion to the bombardment of the vanes by the molecules of gas left in the tube.

The examination of the properties of gases began naturally with the study of air. Similarly the inquiries of the human mind into the characteristics of liquids began with an investigation of the properties of water. The story of Archimedes and the crown problem is probably the earliest historic record of the study of hydrostatics, tho Pliny makes mention of a Phenician who devised a highly ingenious scheme for transporting along the Nile two great columns of an Egyptian temple. The columns were rolled in huge cylindrical boxes, drawn by oxen to the bank of the Nile. There the bank was dug away from under them until they rested on their ends, when two large scows full of sand were floated underneath them. The sand was then thrown out, the boats rose and the pillars took the place of the sand.

No systematic study of displacement and pressure in liquids, however, was made before the time of Blaise Pascal. In 1653 there appeared his "Traité de l'équilibre des Liqueurs," in which he enunciated the law known by his name—to wit:

Pressure applied anywhere to a body of confined liquid is transmitted by the liquid so as to act with undiminished force on every part of the containing vessel.

"Whereby," he said, "it follows that a vessel full of water is a new principle of mechanics and a new machine for multiplying forces to any degree we choose."

The hydraulic press is the direct outcome of Pascal's

Experiment of the Magdeburg Hemispheres.

principle of transmitted pressure. The mechanical advantage of this machine depends simply upon the relative size of the surfaces at which the force is applied and the power produced. If, for instance, the piston of the pump has an area of 10 square inches and the press itself has contact with the water over a surface of 1,000 square inches, the result will evidently be a power 100 times as great as the force. The press will move, however, only $\frac{1}{100}$ as far as the pump piston, for force is indestructible.

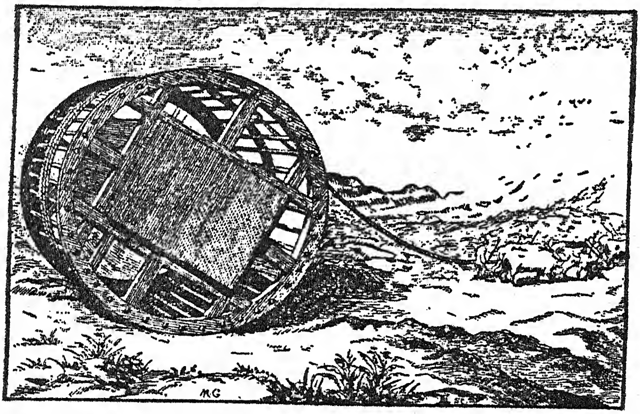


Fig. 9 —ANCIENT MODE OF TRANSPORTING PILLAR.

The particles of a liquid being constantly in motion, it follows that, altho every molecule attracts every other molecule in a vessel of water, yet some of the molecules constantly will be acquiring as a result of collision or temperature a speed which will carry them beyond the attraction of the other molecules. This is what is meant by evaporation. The larger the exposed surface of the liquid the greater the possible number of escaping molecules. This explains why water evaporates so much faster when

boiling than when cool, for the free surface of the liquid is enormously increased by the presence of the bubbles. When a vessel of water is heated, bubbles of gas are first seen to collect around the sides and on the bottom of the vessel. These are bubbles of dissolved air, of which all water contains a certain proportion. As the temperature rises the particles of air, owing to their increased molecular velocities, are forced out of solution, combining to form bubbles. When all the air has been driven out the water at the bottom of the vessel, owing to excessive heating, is vaporized bodily and the phenomenon of boiling appears. The air dissolved in water gets into it in exactly the same way that the water gets into the air—viz., by evaporation. Similarly liquids dissolve in each other, as chlorine or alcohol in water.

Pressure upon the surface of a liquid makes boiling more difficult. The movement of molecules in the liquid and the gas (air) above it will readily explain this fact, for as Robert Boyle showed in the case of gases, that under pressure they have a smaller volume, since the same number of molecules must still be there present, the molecules of gas above the liquid will be closer together and will leave less room for the molecules of the liquid to jump away from the surface. Following this reasoning, it is to be expected that if a vacuum exists above the free surface of a liquid the latter will evaporate more rapidly. Such is indeed the fact, and a very pretty demonstration of it may be made thus: If a watch glass with a little ether in it be placed upon a drop of water under the receiver of an air pump and the latter exhausted of air it will be found at the end of a couple of minutes that the watch glass is frozen fast to the floor of the receiver. The ether evaporates so rapidly under these conditions that the temperature of the water is reduced to freezing. Otto von Guericke remarked that when he had connected a large exhausted receiver to the air space above a cask of wine there followed "a loud boiling noise," which continued for some

time. He did not know how to explain this sound, but to-day, with the aid of the experimenters of nearly three centuries, it would be accounted for by saying that the exhaustion of the air which rushed into the receiver caused such a rapid evaporation of wine in the cask as to produce the phenomenon of boiling. Exactly similar results may be produced by half filling a thin bottle or flask with boiling water. If the flask be now tightly corked and inverted the application of any cool substance, such as a wet cloth or the pouring of cold water over the bottom, will cause a contraction of the vapor-laden air within. This contraction, by relieving the pressure upon the surface of the water, will cause the latter to boil again. The operation may be repeated many times without reheating.

A question naturally suggests itself in this connection, Why is evaporation a cooling process? An answer may readily be found in that extremely serviceable Kinetic Theory of Gases. If the molecules of a gas are traveling, as has been pointed out, in open parabolic paths, these curving orbits are likely to intersect more frequently when the molecules are crowded and jostled together than when left comparatively free and untrammeled. A man walking along a country road feels far less conflict with the surrounding objects of nature than with the busy throng which hustles him and the cares that crowd upon him in the swarming city streets. His mental state is more placid, cooler. So is it with those entities called molecules, and the greater the expansion the more marked will be the fall in temperature.

The question may even be asked as to why a gas expands into a vacuum. For the present an answer must be found in the equilibrium of forces and the fact that particles of matter, like the charged corpuscles of an electric current, or the drops of water in a flowing stream, follow the path of least resistance and move in that direction determined by the sum of the forces acting upon them. On this basis may also be explained the familiar phenomena of capillar-

ity and osmose or diffusion in liquids—the fact that a lump of sugar, if allowed to stand for a while, will sweeten a whole glass of water without stirring.

Evaporation is but an instance of the adjustment of forces to an equilibrium. When the air above a dish of water is confined by a cover, evaporation will proceed only until the vapor is saturated with the particles of water which have jumped out of the dish. When the point of saturation is reached there will be as many molecules leaping back to enter the liquid as those which free themselves from its surface. Evaporation therefore will cease.

In the same way solids whose particles are evaporating from the surface may saturate the air around. If the air is confined, evaporation will cease at saturation. Camphor which is carefully protected from air will act for many months or even years as a deterrent to moths, but if left exposed the rapidity of its evaporation is shown by the fact that a piece of camphor brought into a room may be detected from any part of the room in a few minutes. The exquisite odor of a bunch of roses will quickly perfume a large room, and the perfume of flowers consists of the particles of matter being thrown off by evaporation.

Not greatly unlike the phenomenon of crystallization in the fixation of its molecular particles is magnetism, one of the oldest observed physical phenomena. Pliny says the word "magnet" is derived from the name of the Greek shepherd Magnes, who on the top of Mount Ida observed the attraction of a large stone for his iron crook. It was also known to the ancients that artificial magnets may be made by striking pieces of steel with natural magnets, but it was not until about the twelfth century that the discovery was made that a suspended magnet will assume a north and south position. The compass, said to have been introduced into Europe from China, appeared first about 1190. The incalculable value to the world of this discovery is patent. It meant scientific navigation, exploration and the discovery of the New World.

With Galileo in Italy, "the originator of modern physics," may well be placed William Gilbert, "the father of the magnetic philosophy." Gilbert was appointed by Queen Elizabeth her physician-in-ordinary, and she settled upon him an annual pension for the purpose of aiding him in the prosecution of his philosophical studies. His first investigations were in chemistry, but later, for eighteen years or more, he experimented on electricity and magnetism. In 1600 he published his famous treatise, "De Magnete," in which he showed as the result of careful experimentation that the compass points to the north, not be-

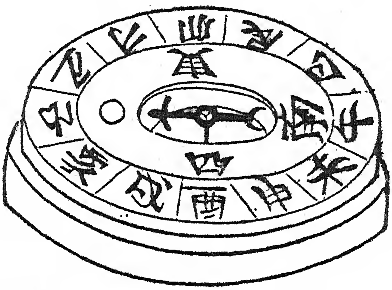


Fig. 10 —Early Chinese Compass.

cause of some mysterious influence of the stars but because the earth is itself a great magnet.

In reading over the six books of this great work, one cannot fail to be struck by the variety of the author's accomplishments. He writes in Latin and intersperses his pages with frequent Greek quotations; he is familiar with poets, historians and philosophers and discusses with clearness and fulness all the chemical and physical knowledge of previous ages. The work is truly monumental. It also contains Gilbert's own numerous valuable and costly contributions to magnetic science. First among these is his grand generalization, "the new and till now unheard of

view," that the earth is a great magnet; and he is not afraid to say that this novel view "will stand as firm as aught that ever was produced in philosophy, backed by ingenious argumentation or buttressed by mathematical demonstration."

Gilbert's contempt for the methods of the schoolmen crops out everywhere in his book. "Why should I," he writes boldly, "submit this noble and this new and inadmissible philosophy to the judgment of men who have taken oath to follow the opinions of others, to the most senseless corrupters of the arts, to lettered clowns, grammatists, sophists, spouters and the wrong-headed rabble, to be denounced, torn to tatters and heaped with contumely? To you alone, true philosophers, ingenuous minds, who not only in books but in things themselves look for knowledge, have I dedicated these foundations of magnetic science—a new style of philosophizing."

Gilbert did not explain, nor has any satisfactory explanation yet been offered, as to why iron and steel are the only substances which exhibit marked magnetic properties. Nickel and cobalt are appreciably attracted by a strong magnet, but the other metals, copper, zinc, tin, lead, etc., show complete indifference to magnetic influence, while bismuth and antimony are actually repelled by it. In this unique restriction of its application to one or two substances magnetism as a force stands alone. It is generally held to be due to a molecular adjustment. The facts that magnetic iron heated red hot and beaten loses its magnetism, that a magnet hung north and south and beaten likewise loses its magnetism, make it apparent that magnetism is due to the arrangement of the molecules of the magnetized body.

The expansive tendency of the molecules of a gas under ordinary conditions of temperature and pressure is quite different from the behavior under like conditions of the molecules of a liquid or a solid. There is every reason to suppose that the molecules of an unconfined gas would

expand indefinitely into space. In accordance with current belief the molecules of every substance are in motion.

"In the solid state," writes a prominent American physicist of to-day, "it is probable that the molecules oscillate with great rapidity about certain fixed points, always being held by the attractions of their neighbors—*i.e.*, by the cohesive forces—in practically the same position with reference to other molecules in the body. In rare instances, however, as the facts of diffusion show, a molecule breaks away from its restraints.

"In liquids, on the other hand, while the molecules are in general as close together as in solids, they slip about with perfect ease over one another and thus have no fixed positions. This assumption is necessitated by the fact that liquids adjust themselves readily to the shape of the containing vessel. In gases the molecules are comparatively far apart, as is evident from the fact that a cubic centimeter of water occupies about 1,600 cc. when it is transformed into steam, and furthermore, they exert practically no cohesive force upon one another, as is shown by the indefinite expansibility of gases."

A highly illuminating discussion of the actual motions of molecules in these three fundamental states of matter has recently been given by J. W. Richards (president of the American Electro-Chemical Society) in an article entitled 'Kinetic Molecular Energy.' Dr. Richards writes: "The conditions of molecular motion is chiefly determined by velocity. According to the velocity of the molecules we have solids, liquids and gases. Within the lowest range of molecular velocity the movement of the molecules is oscillatory; we have a fixed relative position; the body has a size or shape; it is a solid. Within the next higher range of molecular velocity the velocity is able to carry the molecules just beyond the reach of opposing forces; the molecules move in closed elliptic orbits (like the planets round the sun); the body loses its form and shape, but retains its volume; it is a liquid. When the

molecular velocity is raised still farther the molecules move in open parabolic paths; the body not only has no shape or form, but actually tends to increase its volume; it is a gas."

If attraction is exerted between the molecules of a substance it must be conveyed by some medium other than matter. This conclusion is involved in the hypothesis of the granular nature of matter, for force acting at a vacuous distance is unthinkable or at best incomprehensible. The cohesion of the molecules of a substance thus resembles gravity, which reaches across the enormous interplanetary spaces to grasp the masses of the planets and hold them in their courses round the sun; like gravity also the cohesive force which renders substances elastic does not seem to consist of material vibration or ether disturbances. Cohesion acts through infinitesimal spaces upon bodies infinitesimally small; gravity spans distances immeasurable to guide a myriad of suns and systems. Yet both these forces are conveyed through a medium at once infinitely rigid, since it is non-compressible, and infinitely fine, since it is frictionless. The distinguished author of the electro-magnetic theory of light, speaking of the characteristics of the ether, writes:

"The vast interplanetary and interstellar regions will no longer be regarded as waste places in the universe, which the Creator has not seen fit to fill with the symbols of the manifold order of His kingdom. We shall find them to be already full of this wonderful medium; so full that no human power can remove it from the smallest portion of space or produce the slightest flaw in its infinite continuity. It extends unbroken from star to star, and when a molecule of hydrogen vibrates in the dog star, the medium receives the impulses of these vibrations, and after carrying them in its immense bosom for several years, delivers them, in due course, regular order and full tale, into the spectroscope."

CHAPTER III

HEAT

IT has been said that the history of man begins with the discovery of fire. How many conveniences of modern life are dependent in the last analysis upon the use of fire, it would be hopeless to attempt to enumerate. The survival of the human race with its primitive undeveloped physique, helpless for defense or attack except by virtue of superior cunning, would never have been possible without the aid of fire. It is, indeed, a well-known fact that life in any form is directly dependent for its development upon conditions of temperature. The myriad forms of physical life that are hourly born upon the surface of the globe owe their existence to the heat radiated from a gaseous ball, some 93,000,000 miles away.

All heat in the world—excepting the negligible quantity reflected from the moon or transmitted from the stars—must be traced originally either to falling meteorites or to the sun. The warmth of the air, the rocks and the water is derived from these sources. Even the heat of a coal or wood fire is but an expression of solar energy, for it was the sun's heat which, through the growth of vegetable tissue, yesterday, or a million years ago, transformed the incombustible soil into a form apt for the burning.

The heat received by the earth from meteors would be nearly the same in amount as that which it receives from the sun by radiation, but for the probable circumstance that these meteors, reaching the earth's atmosphere at an ex-

ceedingly low temperature, radiate most of the heat engendered in their approach into outer space. For practical purposes, then, the sun may be considered as the original source of all terrestrial heat. No material body, it is true, is quite devoid of heat, for as long as its molecules are in vibration, matter must radiate into the space surrounding this vibratory energy. Heat as a physical phenomenon, then, is the vibration energy of molecules of matter—solid, liquid, or gaseous. Here must be noticed the difference between "radiant heat," so-called, and molecular heat. In the form of radiant heat, energy is transmitted by the sun to the earth. It is converted from radiant heat into molecular vibration upon contact with the matter of the earth, and the material bodies, so incited, afford the phenomenon commonly known as heat.

Anything like an exact study of heat was never possible before the dissociation of the ideas of the vibratory phenomenon of heat and the sensation of it. By the use of his sense of touch mainly, man has learned to decide in a general way whether a body is hot or cold, and whether it is gaining heat or losing it. Conclusions based on this sense of temperature, however, are likely to be very inexact, or even wholly false. The sensation of heat may often be mistaken for that of cold, and vice versa. If one hand is put into ice-cold water and the other into water as hot as it can endure, and after a minute or two both hands are thrust into water at blood-heat (98° F.), this same water will feel cold to one hand and warm to the other. Evidently the temperature sense is a relative matter. Heat as a sensation must be relegated to the domain of medicine or psychology; heat as a form of vibration, however, is a legitimate object of physical investigation.

Previous to the nineteenth century physicists generally considered heat as an invisible weightless fluid, which by passing into or out of a body caused it to become hot or cold. This view accorded readily enough with the facts observed in the heating of a body held in a flame, or near

another hot body. It did not account for the heat produced by friction. In 1798 Benjamin Thompson, Count Rumford, an American by birth, brought forward the molecular theory of heat, according to which the increase in the temperature of a body means simply an increase in the average velocity of its molecules. This theory, tried out and carefully tested by the great English physicist, James Prescott Joule, in an exhaustive series of experiments, has proved thus far the best working hypothesis of the nature of heat.

"The earliest traces of the theory that heat is matter," writes Florian Cajori, "are found in ancient Greece among Democritus and Epicurus. In modern times it was advocated by Pierre Gassendi and Georg Ernst Stahl, author of that erroneous theory of combustion, according to which a burning body gave off a substance called 'phlogiston.' One such agent paved the way for the other. In 1738 the French Academy of Sciences offered a prize question on the nature of heat. The winners of the prize favored the materialistic theory. At first the only properties postulated for this material agent, called heat, were that it was highly elastic and that its particles repelled each other. By this repulsion the fact that hot bodies give off heat could be explained. Later it was assumed that the heat particles attracted ordinary matter, and that this heat was distributed among bodies in quantities proportional to their mutual attractions (or their capacities for heat). By the close of the eighteenth century this theory met with almost universal acceptance." Marat, afterward famous as a leader in the French Revolution, gave in 1780 an exposition of this theory by starting from Newton's corpuscular theory of light.

Professor Clerk Maxwell, in his 'Theory of Heat,' says: "We must therefore admit that at every part of the surface of a hot body there is radiation of heat, and therefore a state of motion on the superficial parts of the body. Now, motion is certainly invisible to us by any direct mode of

observation, and therefore the mere fact of a body appearing to be at rest cannot be taken as a demonstration that its parts may be in a state of motion. Hence, part at least of the energy of a hot body must be energy arriving from the motion of its parts. Every hot body is, therefore, in motion, the movements of the parts being too small to be observed separately."

Tyndall defined heat as "a mode of motion." It might more accurately be defined as "a mode of motion of the particles of a mass;" the greater the heat, the greater will be the motion of the particles. In accordance with the molecular theory discussed in the chapter on the Properties of Matter, any increase in temperature means simply this, and nothing more—an increased velocity of the molecules of the heated substance. If, then, the temperature of a body be lowered until the point of absolute zero is attained, there will then be no motion of its molecules—nothing but mass would remain, absolutely motionless and in a state of perfect tranquillity and rest.

To speculate as to the probable condition of matter when the point of absolute zero has been passed, and the molecular motions have become, so to speak, negative, might be interesting but not profitable. As yet the temperature of absolute zero has never been attained, and all matter as known to-day is possessed of some molecular motion—some heat. The late Lord Kelvin has surmised that the ether may be constituted of the dissipated dust of atoms which have lost all vibratory motion of their own. This is admittedly a guess, and does not affect the generally accepted belief that ponderable matter is ever in vibration.

The measurement of heat may be considered in any one of three ways. It is possible first to measure the degree of heat in a body, as did Galileo with his air thermometer as early as 1592. Measurements of this kind made with solids, liquids and gases have resulted in the establishment of extremely valuable physical data, more especially in the field of meteorology. Secondly, the actual amount of

heat in a body may be measured. It is evident that a red-hot needle possesses a smaller amount of heat than a stove which is only moderately hot. The determination of the amount of heat possessed by a body constitutes the science of calorimetry.

The calorie, or heat unit, is defined as the amount of heat necessary to raise one cubic centimeter of water through one degree Centigrade.

Joule reasoned that if the heat of friction were merely mechanical energy which had been transferred to the molecules of a heated body, then the same number of calories must always be produced by the expenditure of a given amount of mechanical energy. His investigations in calorimetry, whereby he determined the mechanical power corresponding to a given amount of heat, first proved experimentally the identity of various forms of energy. In a series of experiments lasting over nearly 30 years, he caused mechanical energy to disappear in as many ways as possible, and measuring the amount of heat developed, found it to be for a given amount of energy in each case the same. Thus was established the principle of the Mechanical Equivalent of Heat.

The English physicist found that the equivalent of the calorie in work was equal to 426.4 kilogram meters (= 3,081 ft. lbs.), that is to say, the amount of heat necessary to raise 1 cubic centimeter of water 1 degree Centigrade would, if all converted into work, be sufficient to raise 3,081 lbs. through 1 foot of height, or what is the same thing, to raise 1 pound through 3,081 feet. The mechanical equivalent of heat is such an important constant in nature that several physicists since Joule have thought it desirable to redetermine it. One of the most accurate determinations was made in 1879 by Henry A. Rowland of Baltimore. He obtained 427 gram meters as the mechanical equivalent of the calorie.

A third method of measuring the heat of a body is a relative one. Specific heat is a term used in comparing

the relative amounts of heat necessary to increase equally the temperature of equal weights of different substances, for example, glass and water. It has been found that more heat is required to raise the temperature of a pound of water, say 10 degrees, than to increase to the same extent the temperature of an equal weight of almost any other substance. Therefore, water is taken as a standard of specific heat, and when the heat necessary to raise the temperature of glass 10 degrees is found to be five times as great as that necessary to raise the temperature of an equal amount of water 10 degrees, the specific heat of glass is determined at one-fifth or .2. The value to the physicist and chemist of determining specific heats of substances is great, for a fixed relation has been found to exist between the specific heats of solids and their atomic weights. For this significant discovery, science is indebted to the researches of Berzelius, Regnault, Dulong and Petit.

Matter is variously affected by heat. In general, it increases the volume of a body; but just as magnetism has sometimes the contrary effect (as, for instance, its contractile influence upon nickel), so heat has sometimes the effect of reducing a body. Water, for example, is denser at 40° Fahrenheit than at freezing, which is proven by the fact that ice floats, having about one-tenth of its volume out of water. Were it denser than water, this could not be. Again, type metal contains a small proportion of antimony, since antimony expands on solidifying, making the perfectly sharp outline indispensable to good type. With the exceptions noted, however, the law is general that bodies contract with cold, and expand with heat. Railway rails are always laid with a slight space between them to allow for the expansion in the hot days of summer. Iron bridges frequently have a roller at one end to provide for the difference of length. The steel suspension cables of a bridge a mile long will vary in length nearly four feet between summer heat and winter cold. If the heat applied to a substance is strong and continuous, the result is a

change of state; solid ice becomes water, water becomes a vapor. A great deal of energy is absorbed in this transformation of state. It takes nearly as much heat to change a pound of ice into a pound of ice water as to heat the same water to boiling. It takes more than five times as much heat to change the water into steam as to raise its temperature from freezing to boiling. Conversely a great amount of energy is liberated by the condensation of steam —a fact well illustrated in the immense power of the steam engine; and no small amount of heat is set free when water freezes. The country in the neighborhood of large lakes is thus appreciably warmed by the congelation of the water. For exactly the same reason the farmer often places tubs of water in his cellar that the freezing of the water may sufficiently warm the air to keep his vegetables from freezing.

More remarkable than the effect of the freezing of water upon the surrounding air, is that of evaporation. As the freezing of water in winter warms the air, so the evaporation of water in the open seasons of the year will cool it. The amount of evaporated water which can exist in the air depends upon the temperature. If the air has absorbed all the water vapor which it is capable of holding, it is evident that a fall in temperature will succeed in condensing a part of the suspended water-vapor which then falls as rain, or settles as mist. If the air is not completely saturated, it is evident that considerable cooling may take place before the "dew-point" is reached and condensation of water begins. In the hot days of the summer months the air is capable of taking up and holding in suspension a large amount of moisture. On such days the oppressiveness of the heat is greatly augmented by the "muggy" condition of the atmosphere. The excessive moisture of the human body cannot escape into the air, for the latter is already surcharged with moisture, or nearly so. The grateful effect of a breeze is thus made clear, for the excess of moisture which evaporates from the body has no

the relative amounts of heat necessary to increase equally the temperature of equal weights of different substances, for example, glass and water. It has been found that more heat is required to raise the temperature of a pound of water, say 10 degrees, than to increase to the same extent the temperature of an equal weight of almost any other substance. Therefore, water is taken as a standard of specific heat, and when the heat necessary to raise the temperature of glass 10 degrees is found to be five times as great as that necessary to raise the temperature of an equal amount of water 10 degrees, the specific heat of glass is determined at one-fifth or .2. The value to the physicist and chemist of determining specific heats of substances is great, for a fixed relation has been found to exist between the specific heats of solids and their atomic weights. For this significant discovery, science is indebted to the researches of Berzelius, Regnault, Dulong and Petit.

Matter is variously affected by heat. In general, it increases the volume of a body; but just as magnetism has sometimes the contrary effect (as, for instance, its contractile influence upon nickel), so heat has sometimes the effect of reducing a body. Water, for example, is denser at 40° Fahrenheit than at freezing, which is proven by the fact that ice floats, having about one-tenth of its volume out of water. Were it denser than water, this could not be. Again, type metal contains a small proportion of antimony, since antimony expands on solidifying, making the perfectly sharp outline indispensable to good type. With the exceptions noted, however, the law is general that bodies contract with cold, and expand with heat. Railway rails are always laid with a slight space between them to allow for the expansion in the hot days of summer. Iron bridges frequently have a roller at one end to provide for the difference of length. The steel suspension cables of a bridge a mile long will vary in length nearly four feet between summer heat and winter cold. If the heat applied to a substance is strong and continuous, the result is a

change of state; solid ice becomes water, water becomes a vapor. A great deal of energy is absorbed in this transformation of state. It takes nearly as much heat to change a pound of ice into a pound of ice water as to heat the same water to boiling. It takes more than five times as much heat to change the water into steam as to raise its temperature from freezing to boiling. Conversely a great amount of energy is liberated by the condensation of steam —a fact well illustrated in the immense power of the steam engine; and no small amount of heat is set free when water freezes. The country in the neighborhood of large lakes is thus appreciably warmed by the congelation of the water. For exactly the same reason the farmer often places tubs of water in his cellar that the freezing of the water may sufficiently warm the air to keep his vegetables from freezing.

More remarkable than the effect of the freezing of water upon the surrounding air, is that of evaporation. As the freezing of water in winter warms the air, so the evaporation of water in the open seasons of the year will cool it. The amount of evaporated water which can exist in the air depends upon the temperature. If the air has absorbed all the water vapor which it is capable of holding, it is evident that a fall in temperature will succeed in condensing a part of the suspended water-vapor which then falls as rain, or settles as mist. If the air is not completely saturated, it is evident that considerable cooling may take place before the "dew-point" is reached and condensation of water begins. In the hot days of the summer months the air is capable of taking up and holding in suspension a large amount of moisture. On such days the oppressiveness of the heat is greatly augmented by the "muggy" condition of the atmosphere. The excessive moisture of the human body cannot escape into the air, for the latter is already surcharged with moisture, or nearly so. The grateful effect of a breeze is thus made clear, for the excess of moisture which evaporates from the body has no

opportunity to saturate the air immediately around, before a fresh supply of air appears to take up the exhalation from the skin. It was formerly held by scientific inquirers that the dew fell from the upper regions of the atmosphere. That idea has been quite swept away within recent times, and it is now known that the formation of dew is due to the condensation of water-vapor in the air close to the ground. A heavy dew is said to be the forerunner of fine weather. It actually indicates an unusual fall in temperature from the heat of the day—nothing more.

The formation of condensed particles of water-vapor in the upper regions of the atmosphere is generally conceded to be due to the impalpable dust particles which float everywhere in the terrestrial atmosphere rising to considerable heights. As water vanishes so strangely into the thin vapors of the air, so solid bodies have been observed by every one to disappear and dissolve in liquids.

There are probably few persons, if any, who have not noticed that sugar dissolves more readily in hot water than in cold, while salt is about equally soluble in both. In general, the solutions of solids in water or any other solvent are made easier by the application of heat. So also with solutions of liquids, for the viscosity of most liquids is reduced by the application of heat, they become less dense, and therefore mix more readily with the molecules of the liquid in which they are dissolved. Solution is such a familiar, everyday phenomenon that the complete disappearance of solid material in a liquid is taken as a matter of course. Yet it is truly a wonderful thing that a lump of sugar or a teaspoonful of salt dissolved in a glass of water will not raise the level of the water, and so soon as solution is complete will leave absolutely no visible trace of its presence. As the temperature is raised more of the solid may be made to disappear. Even boiling water, however, will take up but a limited quantity of a solute, and on cooling this may readily be seen by dropping in a crystal of the dissolved material or otherwise disturbing

the mixture, causing it to exhibit the beautiful and fascinating phenomenon of crystallization.

A strange contrast to this condition of things is found in the fact of the solution of gases in liquids. Here the effect of temperature is quite the reverse of what has just been observed. The cooler the liquid, the greater the quantity of gas which may be dissolved in it. The quantity of gas which may be dissolved by a single pint of water is amazing, in some instances almost incredible. Hydrogen chloride, for example, is soluble to the extent of over 300 pints in a single liter of water; and the same quantity of water will dissolve without artificial pressure 1,148 pints of ammonia gas.

The effect of heat on a liquid—or indeed on any body—being recognised as an increase of its molecular velocities, the question arises as to how this increase of velocity is transferred from one part of matter to another. The most direct way for this to take place is by the transference of energy from one molecule to the next. In general this is accomplished most readily by the molecules of a solid, especially solids of exceptional density such as metals. For example, a short copper or iron wire held for a moment in a hot flame soon becomes too hot at the other end to hold. A silver wire will conduct the heat of the flame to the hand even more quickly. A stone feels colder to the hand than a piece of wood at exactly the same temperature, for the obvious reason that the stone, being a better conductor, carries off the heat of the body more rapidly. The tongue will freeze fast in winter to the blade of an ax, a fact well known in cold countries where the bit of a horse's bridle cannot be put directly in his mouth if it has been out in the frosty air. The same ax blade lying in the summer sun will feel hotter than any other part of the ax.

Liquids, however, are poor conductors, as has been shown by the fact that burning alcohol on the surface of water will register no perceptible heat in an instrument so

sensitive as the air thermometer whose bulb is placed but half an inch below the surface of the water. Gases are almost non-conducting. "Dry air," writes a physicist of to-day, "is a practical vacuum as regards the rays of heat."

Liquids and gases, however, may carry considerable heat by the motions of comparatively large masses of themselves in a heated condition. This transference of heat by the movement of masses of a liquid or gas is termed "convection." The term thus describes the manner in which temperature is adjusted by winds in the atmosphere and currents in bodies of water.

Yet another method of the conveyance of heat is that by which most heat in the universe is carried—viz., radiation. The heat which is received from an open fire is not carried by conduction or convection. Not by convection, for the movement of masses of air is all toward the fire, not away from it; not by conduction, for gases have been shown to be very poor conductors. The only other possible explanation of the passage of the heat rays must then be found in a non-material form of energy. To this form of heat transference the term "radiation" has been applied. Radiation thus explains the sensation of heat felt from a burning house, even when the house is at a considerable distance and the wind is blowing toward the fire. The method by which the heat of the sun is conveyed to the earth will likewise readily be seen to be the method of radiation. There could evidently be no mass movements nor yet molecular movements where is neither mass nor molecule. This radiant property must then be a function of the ether, not of matter in the mass. According to recent scholars, radiant heat must now be classed with light under the head of electricity.

The three forms of heat transference—conduction, convection, radiation—are all to be seen in the consideration of the common steam or water radiator. Convection brings masses of hot water or steam from the furnace to the radiator. Conduction transfers the heat to the outside of the

radiator. Radiation carries the heat to every part of the room to be heated.

The application of heat to mechanical purposes has been astonishingly slow of development. From the time of the invention of Heron's eolipile there elapsed 1,000 years before the idea of heat as a source of motive power was turned to practical account. Steam fountains were designed in the seventeenth century, but they were merely modifications of the eolipile and applied for ornamental purposes only.

The first successful attempt to combine the principles and forms of mechanism then known into an economical and convenient machine was made by Thomas Newcomen, a blacksmith of Dartmouth, England. Assisted by John Calley, Newcomen constructed an engine—an "atmospheric steam engine." In 1711 such a machine was set up at Wolverhampton for the raising of water. Steam passing from the boiler into the cylinder held the piston up against the external atmospheric pressure until the passage between the cylinder and boiler was closed by a cock. Then the steam in the cylinder was condensed by a jet of water. A partial vacuum was formed and the air above pressed the piston down. This piston was suspended from one end of an overhead beam, the other end carrying the pump-rod. The fly-wheel was introduced in 1736 by Jonathan Hulls.

The next great improvements were introduced by James Watt in Scotland. Becoming interested in the steam engine and its history, he began to experiment in a scientific manner. He took up the study of chemistry under the guidance of Joseph Black, the originator of the doctrine of "latent heat." Observing the great loss of heat in the Newcomen engine, due to the cooling of the cylinder by the jet of water at every stroke, he began to ponder on the possibility of keeping the cylinder "always as hot as the steam that entered it." He himself tells how there flashed through his mind the happy thought of how this could be done. "I had gone to take a walk," he says, "on a

fine Sabbath afternoon. I had entered the Green by the gate at the foot of Charlotte Street and had passed the old washing-house. I was thinking upon the engine at the time, and had gone as far as the herd's house when the idea came into my mind that, as steam was an elastic body, it would rush into a vacuum, and if a communication were made between the cylinder and an exhausted vessel, it would rush into it and might be there condensed without cooling the cylinder."

This improvement it is by right of which James Watt may justly be called the "inventor" of the steam engine. The steam engine as such has practically reached its maximum of efficiency. Only about 22 per cent. of the heat energy furnished by the coal consumed is actually converted into work, even in the best triple expansion engines. The efficiency of the locomotive is even lower, being about 17 per cent.

The steam turbine, the latest development of the steam engine, is in principle very much like the common windmill, the steam being driven at an angle against a multitude of little blades set into a revolving cylinder of steel—the shaft. In large sea-going vessels this engine is rapidly replacing the old-fashioned "reciprocating" machine, for its efficiency is higher, it occupies less than one-tenth the floor space and it runs without jarring the ship. The highest speeds ever attained by vessels at sea—namely, about forty miles per hour—has been made with the aid of steam turbines. The construction of a turbine is an exceedingly difficult operation, for each of the little blades must be set singly into the shaft at exactly the right angle. Skilled workmanship and much time are required in this operation, and in view of the mechanical difficulties of constructing a turbine, it does not seem so remarkable that this engine, of which the extremely simple principle was familiar to Hero of Alexandria (120 B.C.), should have waited over 2,000 years to see perfection.

The efficiency of the steam engine is measured by the

fall in temperature which the steam undergoes in passing from the boiler through the cylinder (thus driving the pistons) to the condenser. It is evident that as this heat is made to disappear, work must be produced. The greater the fall in temperature, then, the higher the efficiency of the engine. Unfortunately the steam engine is limited in this

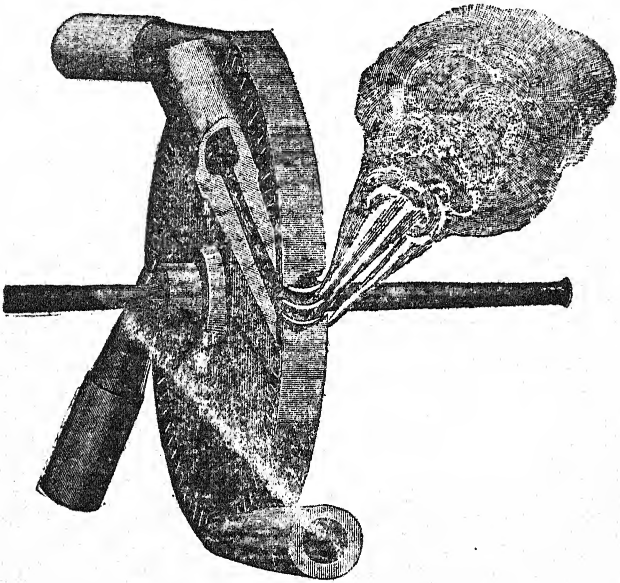


Fig. 11 —Principle of the Turbine.

regard, for the highest temperature that can safely be maintained in the boiler is about 200° Centigrade, the steam being then under a pressure of 15 atmospheres, or 225 pounds upon every square inch of surface. The lowest practicable limit of temperature in the condenser is about 30°. Hence the loss of heat and the resulting efficiency

will be measured by a fall of 170° (200° — 30°). A perfect steam engine should render about 36 per cent. of its heat energy into work, but owing to friction and other causes no steam engine has ever been made which approaches this degree of efficiency.

The gas engine has a considerably larger range of temperature fall possible in its mechanism. The explosion of the gases takes place at a very high temperature. Engineers predict that the gas cylinder engine and turbine engine will before long supplant the corresponding types of steam-driven machines.

In conclusion, then, heat must not be considered as a weightless fluid, for the interchange of heat and mechanical energy is not consistent with this belief. Nor is heat "latent" any more than the lifting power of a steam crane is latent. All the evidence of to-day points to the conclusion that heat is only one of the many forms of vibration.

The effect of heat upon any material body is an increased rate of vibration of its molecules. The heat that reaches the earth from the sun, however, traverses the intervening space without heating it, as the intense cold of the upper regions of the atmosphere clearly indicates. It is therefore a property of the ether that it transmits vibrations without being itself affected by them. In matter, on the other hand, all parts of a conductor must become hot when heat is transferred from one end of it to the other. Convection cannot be considered as a form of vibration at all, since it does not represent the transmission of energy from particle to particle of a mass so much as the change of location of a relatively large amount of heat. It cannot proceed, however, without the aid of either conduction or radiation, inasmuch as the heat given by one mass to another can be received only through the medium of matter or ether. As before observed, ether-borne heat energy is now regarded as nothing more or less than electricity.

CHAPTER IV

THE SOURCES OF LIGHT

RISING from underneath the world, and flooding all nature with the growing splendor of its Light, the morning sun has ever been to man a symbol of the power of goodness. The unparalleled poetic imagination of the Greeks clothed this symbolic object with personal attributes, and formulated the fiery chariot and flying steeds of the Sun God Apollo, the Baldur of the Norsemen, the Christ of early German legend. A growing Christianity synchronized with the effacement of the personal and divine attributes of Light. The third century in Europe saw the development of an established Church—Christian, and an established Science—Greek. The Properties of Matter, Light, Sound, Heat, as defined by Aristotle, became the accepted creed of Europe.

A science not less dogmatic than theology ruled the thoughts of men until near the end of the sixteenth century, until Roger Bacon and Bruno and Galileo, with other less illustrious but not less courageous investigators, had suffered contempt and persecution, and even languished in prison for the splendid heresy of Experimental Truth. The conception of Force—intangible, irresistible, indestructible—was long in making its way into any system of popular philosophy; the world, as a cosmos of Substance possessed of varying Qualities, was all-sufficient explanation for medieval thought of the phenomena of Sense and the fabrications of Reason.

Light, like other things now conceded to be forms of force, was deemed a substance or a quality of substance. Generally it was held to be a substance, possessed, like other substances, of such qualities as elasticity (reflection) and solubility (absorption). The law of the angle of incidence and reflection was known to the Egyptians and the Greeks; the Assyrians were familiar with the lens; the Arabs imitated from Greece and developed a system of optics involving a knowledge of mirrors, plane and spherical, lenses and prisms, the straight-line propagation of light, shadows and semishadows, or penumbræ.

That light travels in straight lines was one of the articles of faith of the Platonic school. Not all the Greek philosophers, however, maintained this view, and the variance of their opinions foreshadowed the uncertainty concerning light which has characterized all subsequent discussion of its exact nature. Aristotle wrote more voluminously than any of the Greeks upon this question, but his conclusions are dubious and obscure. Through his influence the Scholastics were led to regard light as something immaterial, rather a quality of bodies than a substance, and they sought to find in the bodies themselves something analogous with the color sensation of the eye. Both Euclid and Plato, however, conceived of light as a something projected from the eye upon an illuminated body, causing sight as soon as it met another substance which emanated from the body. Pythagoras and Democritus held that visible bodies projected something into the eye whereby they became visible.

The Greeks knew something of spherical and parabolic mirrors. The story is told of Archimedes that when the Romans were besieging his native city, Syracuse, he defended it by the use of mirrors reflecting the sun's rays, which focused upon the ships of the Romans as they came near, setting them on fire. The terrific heat developed in a modern solar engine makes this tale not so impossible as might at first sight appear, altho it is likely that

the men, rather than the ships of the Romans, were the sufferers under the fierce reflection from the mirrors of the Greeks.

That the latter had gathered much other evidence with regard to the phenomena of light is unquestioned, for in a fragment of a Greek document discovered in Egypt mention is made of various familiar optical illusions. They had observed, for example, that a ring on the bottom of an empty vessel, just hidden by the edge, becomes visible when water is poured into the vessel, and Cleomides observed that in the same way the sun may be visible when it has actually sunk below the horizon. The Greeks had noticed, also, that the sun appears larger when rising or setting than when high in the heavens; they were familiar with the fact that light glances off from a mirror at the same angle as that at which it strikes.

Among the Romans no investigators of natural phenomena appeared to add anything of moment to the discoveries of the Greeks. Lucretius made some interesting comments on magnetism; Seneca observed and taught the identity of the colors in the edge of a piece of glass with those of the rainbow; he did not explain why they were identical; he remarked that a globular glass vessel, full of water, magnifies objects, from which he was led to conclude that there is nothing so deceptive as sight, an inference not particularly ingenious nor highly illuminating as an explanation.

Abû 'Alî al Hasan ibn al Hasan ibn Al Haitam rose into favor under one of the Caliphs of Egypt as a result of a plan (which he never carried out) to regulate the flow of the Nile for purposes of irrigation. He made a study of plane and spherical mirrors, and understood, also, the principle of parabolic reflectors, such as are used to-day in searchlights or the headlights of locomotives, in which all the rays leave the mirror in parallel lines. He knew that a ray of light is flashed back from the

surface of water at the same angle as that at which it strikes; he knew, also, that a beam of light entering water is bent from its course—refracted, to use the modern tern. He was aware of the fact of the apparent enlargement of the sun's diameter on approaching the horizon, and correctly explained it as due to the fact that the sun's diameter is then estimated by the size of less distant terrestrial objects, a view admitted by most scientists to-day. Al Hazen (as he is more briefly known) also first described the human eye with exactitude of detail, and originated the famous and difficult problem in optics known as Al Hazen's problem: "Given the position of a luminous point and of the eye, to find the spot at which reflection takes place on a spherical, cylindrical or conical mirror."

Earlier even than the mirror appears the record of the lens. Among the ruins of Nineveh is reported to have been found a lens of rock crystal. Burning-glasses were manufactured at an early date in Greece. In Aristophanes' comedy of The Clouds is found mention of "a fine transparent stone with which fires are kindled," and by which, standing in the sun, one can, "tho at a distance, melt all the writing" on a waxen tablet of the times.

From the millennium of the beginning of this era European thought for 500 years plodded blindly along the road that Grecian philosophy had pointed. Roger Bacon, the one great man in all his time who dared to make a place for original thought and experimental science, was crushed to silence by a ten years' imprisonment for heresy. Petrus Ramus in Paris was forbidden, on pain of corporal punishment, to teach or write against the great Aristotle. With Petrus Ramus must likewise be mentioned Franciscus Patritius, a learned Italian, fiercely persecuted by the Aristotelians on account of his heretical theory that Light and Darkness together produce Warmth and Cold.

From the various theories of the philosophers of Greece it is evident that the Nature of Light, even in those early

times, was a much-mooted question. Previous to the time of Newton opinions as to its exact constitution were divided; some held it to be a real substance, others, especially the followers of Aristotle, considered it a property or quality of matter. Early in the seventeenth century Descartes formulated a new hypothesis as to the nature of light. He held that it is neither material nor a property of matter, but a vibration of that something of which matter is composed, its "second element." He assumed that the whole universe is filled with minute spheres of this elemental substance. Through the constant motion of the particles of luminous bodies these little spheres are jarred, and since there is no empty space in the universe beside them, one sphere immediately touching another, this jar or disturbance is immediately distributed in straight lines. As an explanation of this thesis he compares the propagation of light with the motion imparted to the whole length of a stick when one end of it is pushed. A similar disturbance, in his opinion, may be caused by the eye, from which he explains how cats and other animals whose eyes glitter can see in the dark. Against this Cartesian hypothesis it has been urged that through these rows of spheres light would be propagated, not in straight lines alone, but in every direction, as pressure is transmitted in all directions by water. Descartes, however, had a large following for a time in his belief as to the nature of light.

Later appeared two main theories of light, viz., the Corpuscular Theory and the Undulatory Theory. The former theory was essentially that of the Greeks, altho they adorned it with various fanciful hypotheses. The great exponent of this theory in more recent times was Sir Isaac Newton, who based his acceptance of it on the conviction that the rectilinear propagation of light was explainable only on this basis. Sound waves, he argued, may be heard around corners; water waves swing round a jutting point of land. Since light travels in

surface of water at the same angle as that at which it strikes; he knew, also, that a beam of light entering water is bent from its course—refracted, to use the modern tern. He was aware of the fact of the apparent enlargement of the sun's diameter on approaching the horizon, and correctly explained it as due to the fact that the sun's diameter is then estimated by the size of less distant terrestrial objects, a view admitted by most scientists to-day. Al Hazen (as he is more briefly known) also first described the human eye with exactitude of detail, and originated the famous and difficult problem in optics known as Al Hazen's problem: "Given the position of a luminous point and of the eye, to find the spot at which reflection takes place on a spherical, cylindrical or conical mirror."

Earlier even than the mirror appears the record of the lens. Among the ruins of Nineveh is reported to have been found a lens of rock crystal. Burning-glasses were manufactured at an early date in Greece. In Aristophanes' comedy of The Clouds is found mention of "a fine transparent stone with which fires are kindled," and by which, standing in the sun, one can, "tho at a distance, melt all the writing" on a waxen tablet of the times.

From the millennium of the beginning of this era European thought for 500 years plodded blindly along the road that Grecian philosophy had pointed. Roger Bacon, the one great man in all his time who dared to make a place for original thought and experimental science, was crushed to silence by a ten years' imprisonment for heresy. Petrus Ramus in Paris was forbidden, on pain of corporal punishment, to teach or write against the great Aristotle. With Petrus Ramus must likewise be mentioned Franciscus Patritius, a learned Italian, fiercely persecuted by the Aristotelians on account of his heretical theory that Light and Darkness together produce Warmth and Cold.

From the various theories of the philosophers of Greece it is evident that the Nature of Light, even in those early

times, was a much-mooted question. Previous to the time of Newton opinions as to its exact constitution were divided; some held it to be a real substance, others, especially the followers of Aristotle, considered it a property or quality of matter. Early in the seventeenth century Descartes formulated a new hypothesis as to the nature of light. He held that it is neither material nor a property of matter, but a vibration of that something of which matter is composed, its "second element." He assumed that the whole universe is filled with minute spheres of this elemental substance. Through the constant motion of the particles of luminous bodies these little spheres are jarred, and since there is no empty space in the universe beside them, one sphere immediately touching another, this jar or disturbance is immediately distributed in straight lines. As an explanation of this thesis he compares the propagation of light with the motion imparted to the whole length of a stick when one end of it is pushed. A similar disturbance, in his opinion, may be caused by the eye, from which he explains how cats and other animals whose eyes glitter can see in the dark. Against this Cartesian hypothesis it has been urged that through these rows of spheres light would be propagated, not in straight lines alone, but in every direction, as pressure is transmitted in all directions by water. Descartes, however, had a large following for a time in his belief as to the nature of light.

Later appeared two main theories of light, viz., the Corpuscular Theory and the Undulatory Theory. The former theory was essentially that of the Greeks, altho they adorned it with various fanciful hypotheses. The great exponent of this theory in more recent times was Sir Isaac Newton, who based his acceptance of it on the conviction that the rectilinear propagation of light was explainable only on this basis. Sound waves, he argued, may be heard around corners; water waves swing round a jutting point of land. Since light travels in

straight lines, the great philosopher concluded that it must be due to the projection from luminous bodies of extremely minute particles or corpuscles at a tremendous speed.

A contrary view was advocated by Christian Huygens about the end of the seventeenth century. This famous Dutch physicist regarded light, like sound, as a form of

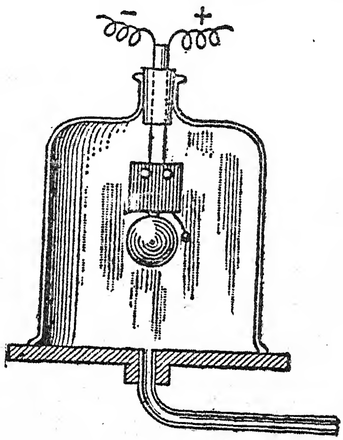


Fig. 12 —Bell Cannot be Heard in Vacuum.

wave motion. A very serious difficulty confronted this theory at the outset. Sound, as is well known, cannot traverse a vacuum. Von Guericke, the Madgeburg Magician, had shown, some years previously, that a clock cannot be heard to strike in a receiver exhausted of air. Light, however, can be seen through such a vacuum without difficulty, and travels without perceptible retardation through the enormous interstellar spaces—possibly vacua—infinitely better than can be gotten by the best means artificially. Some medium, Huygens reasoned, must be there to transmit these vibrations. He boldly assumed

such a medium and called it the Luminiferous or Light-bearing Ether. The fact that other forms of undulatory motion, such as sound waves and water waves, can sweep around corners, he did not explain.

At first sight the corpuscular theory of light would seem to be by far the simpler and more obvious explanation of the two, and for more than a hundred years the weight of Newton's authority threw the balance in favor of this theory. So many facts opposed to this theory have appeared, however, in modern experimentation that the corpuscular theory is to-day practically abandoned. Light is admittedly a form of vibration.

Light, it has been said, is a form of vibration, but it is evidently not the same vibration as that which takes place in the molecules of a heated conductor; nor is it the same as the series of condensations and rarefactions of the air that is called sound. These latter are vibrations of matter, and light is evidently a vibration of a different nature, for no amount of light applied to one side of an iron door will shine through to the other side. Heat, on the contrary, or sound will very quickly be transferred by conduction to the farther side of the door. Light as it reaches the earth from the sun must be considered as something closely analogous to radiant heat, if not identical with it. Recent study of the effects of radiation show that light and radiant heat are actually the same. Modern theory regards light as a form of radiant heat whose wave lengths are such that they directly affect the optic nerve.

The great source of light on the earth—far transcending all others—is the sun. It is by no means the only source. The moon, tho intermittent in the amount of its light and shining in full radiance for only a few nights each month, must nevertheless be reckoned as a valuable adjunct illuminant to the sun. The light from stars and planets, too, is considerable. Walter Hough, in his 'Development of Illumination,' says: "Under the clear night sky of the Arizona deserts the atmosphere seems charged with star

mist; eminences miles away may be outlined, the dial of a watch may be read, and a trail followed with little difficulty. These are the conditions under which night journeys are made to avoid the burning sun." The planet Venus, he continues, at certain times sheds light sufficient for the traveler over open country.

"There are at times nights of remarkable luminescence. Clouds become phosphorescent, and often under certain states of electric stress, during high winds, glimmer with a faint light not amounting to a discharge of the electric fluid. Frequently successive flashes of 'heat lightning' aid the traveler in finding his way. It is possible, also, that the soil over certain regions may become phosphorescent under the light of the sun and retain the property during the night, as certain gems are phosphorescent after being submitted to sunlight. Snow has this property. Gaseous emanations of a phosphorescent character are occasionally abundant enough to produce temporary illumination, and the phosphorescent light of tropical seas has drawn forth many remarks on its beauty."

Most of the work in the cities of to-day is done by diffused light. The direct rays of the sun are found, in almost all cases, too powerful for purposes of reading or writing, but the diffused light reflected in a thousand different directions from all surfaces not perfectly black or smooth supplies an abundance of light, soft, yet bright enough for use. Since the introduction of artificial illuminants it has ever been the aim of inventors to produce a light resembling this diffused daylight. The old sperm oil lamps and tallow dips of Europe which came over with the colonists to America were there superseded by petroleum lamps. The addition of the argand chimney of glass —the invention of which dates back only to about 1780— facilitated the development of the first really practical artificial illuminant. Even to-day this old type of chimney and burner may be seen in the 'student lamp,' so popular for reading purposes. The invention of the argand lamp,

with the brilliantly luminous kerosene, soon made night reading a general practice. Everybody could now read—even the poor—and everybody did. It is an interesting coincidence that is brought out by a recent writer on illumination, Dr. David T. Day, that the progress of the countries of the civilized world to-day is in nearly every case directly proportional to their consumption of kerosene.

The arc lamp and incandescent light of Edison marked a step forward toward the production of an ideal artificial light. But the arc light is not constant, and even when surrounded with a large globe not sufficiently diffused for reading purposes; the incandescent bulb, notwithstanding the improved tantalum and osmium filaments gives a glare too concentrated for ease in working. The nearest approach to diffused daylight has been made in the Hewitt mercury vapor lamp, where a small quantity of mercury in a long vacuum tube is first vaporized and then rendered luminous under the influence of the electric current. This lamp, however, is open to objection on the ground of its color. The ideal lamp has yet to appear.

CHAPTER V

THE SPEED OF LIGHT

AMONG all the properties of light none is more striking than its speed. Previous to the seventeenth century this had always been supposed to be infinite, and the discovery of the gradual propagation of light is one of the most wonderful achievements of that wonderful period in the history of physics—the Renaissance. The first attempt to measure the speed of light was made by Galileo. He ascertained the time for one person to signal with a lamp to another and receive back the signal. The experiment was tried at night, when the two observers were close together and again when they were nearly a mile apart. If a difference in time could be detected, then light would travel with finite velocity. Galileo was not able from his experiments to settle the question.

About thirty years later a young Dane, Olaf Römer, was observing the eclipses of Jupiter's moons.

It was noticed that the times of revolution of these moons in their orbits were not the same at all periods of the year, and were greater than the average when the apparent size of Jupiter was diminishing. Considering it in the highest degree improbable that the actual motions should be affected with any inequality of this sort, Römer became convinced that the observed irregularities must be explained on the supposition that the velocity of light is finite. He said that the discrepancy could be accounted for by assuming that it took time for light to come from

Jupiter to the earth. On November 9, 1676, an eclipse took place at 5 h. 35 m. 45 s., while by computation it should have been at 5 h. 25 m. 45 s. On November 22 he explained his theory to the French Academy more fully, and said that it required light 22 minutes to cross the earth's orbit. (The more correct value is now known to be 16 minutes and 36 seconds.) Like the news of so many other great discoveries, Römer's announcement fell upon deaf ears. It was fifty years before the scientific world recognised the truth and the value of his contribution to knowledge.

Römer computed the velocity of light to be 309,000 kilometers (about 186,000 miles) per second. Subsequent determinations made by astronomers and physicists have corrected this computation but little. The most accurate estimates of this figure are those made by Jean Léon Foucault, inventor of the gyroscope and originator of the Foucault pendulum, in France, and Albert R. Michelson, of the United States Navy, in America. The speed found by Michelson as the result of more than a hundred trials, lasting over some two months of daily experimentation, averaged 299,740 kilometers, or 186,300 miles per second. The speed of light in a vacuum is estimated as but slightly greater than in air.

The velocity of light in water was a pregnant question in determining the true nature of light. The discussion of this problem belongs to very recent times. It shows what remarkable influence the opinions of Isaac Newton exercized, and illustrates how easy it is even for scientific men to "take sides" in a discussion where only truth is sought. According to the adherents of the Newtonian school the speed of light in water—a denser medium than air—should be greater than its speed in air, just as the speed of sound in iron is greater than in wood. But if light be a vibrational phenomenon the speed should be less in water than in air. This was the fact which the exponents of the undulatory theory—of whom Thomas

Young in England and Fresnel, Malus and Foucault in France were the leading lights—were called upon to demonstrate if the Newtonian theory was to be refuted. Foucault took up the idea, constructed a sort of "light siren" which made more than 1,000 revolutions per second, and reflecting a beam of light showed a deviation of the ray upon a mirror at a distance. This deviation he found to be greater when the ray of light was passed through water, and his experiment gave conclusive proof that the Newtonian theory of light was false. The speed of light in water was found to be just about three-fourths of the speed in air. That light in passing from air through a dense medium, such as water or glass, suffers a retardation, was a natural inference.

That a distant light gives less illumination than one which is near was early a fact of common observation. The exact extent to which distance would affect the amount of light received, however, is not so generally known. The earth receives a certain amount of light from the sun, an amount varying with the latitude and the seasons. At first blush it might seem as if this light would increase in direct proportion to the nearness to the sun, as if, supposing the earth were half as far away, the light would be twice as great, and the heat received on the earth would only be doubled. That such is not the case is now known to every student of the elements of physics.

It has been estimated, indeed, that if the earth were moved half way from its present position toward the sun, the whole face of nature would be changed. Life as it now exists would be impossible—no trees, grass, or any verdure would cover the face of the earth; water would be unknown, existing only as a prodigious enveloping veil of vapor through which the sun's rays would pass with considerable loss of energy. Enough would be transmitted, however, so that metals such as tin and lead and even zinc would be liquids, mercury a gas, sulphur a boiling fluid mass. An intense glare would illuminate the

glowing rocks and naked soil—a light the like of which cannot be conceived by aid of any comparison with the physical world of to-day. And yet the sun would then be distant more than forty millions of miles from the surface of the earth. How bright must be the illumination which the sun casts upon the little planet Mercury, so much nearer to him than the Earth, it is utterly impossible to imagine. There is no standard of comparison. Yet Mercury is distant 37,000,000 miles from the sun.

The sense of perspective is a universal faculty. A ship grows continually smaller in approaching the horizon; a near-by fly crossing the path of vision looks larger than an eagle; a penny held close to the eye will obscure the world. Light, as before observed, travels in straight lines from every illuminated point. From a lighted candle rays of light radiate in every direction straight away from the flame. The artist familiarly represents the light of a candle by an illuminated circle around it, which rapidly shades from white to dark gray or black shadow. This iluminated circle represents in reality a hollow sphere or shell of light, and each radiant vibration coming from the source of light is spread over the surface of the sphere. It is a well-known fact that if the radius of such a sphere be made to increase, the area of the sphere will also increase, but much faster than the radius—in fact, as the square of the latter. The surface of a two-inch ball is four times as great as that of an inch ball; the surface of a three-inch ball is nine times as great as that of an inch ball. Similarly the light which from a point within would reach the surface of a hollow sphere one foot in diameter would be spread over nine times the same area if the radius of the sphere were three feet. Hence each point on the surface of the larger sphere would receive only one-ninth as much light.

The amount or intensity of light, then, varies not exactly as the inverse of the distance, but inversely as the square of the distance from the source of light. In gen-

eral, as any light wave advances its energy is being distributed over a surface which increases directly as the square of the distance the wave has traveled. It must be noted, however, that this law of intensity applies only to the direct light from a luminous body; for the total illumination on a given surface is usually very much increased by the light reflected from near-by non-luminous bodies. Hence it is that white walls and furnishings add so much to the total amount of light in a room. The law of the Intensity of Light is evidently analogous to that of gravity, where it was seen that a pound weight at the surface of the earth (4,000 miles from its center) would weigh only ¼ lb. at the distance of 4,000 miles from the surface (8,000 miles from its center, or twice as far away as at the surface). It is this strangely persistent law of inverse squares which, more than any other fact of physics, points to the ultimate unification of all Force under one head. The law holds true for gravity, electric and magnetic attraction and repulsion, light, sound, heat and so-called "radiant heat," together with numerous other less fundamental physical relationships.

An ingenious yet extremely simple instrument for measuring the amount of light received from a given source was invented about the end of the eighteenth century by an American, Benjamin Thompson, afterward Count Rumford. In front of a ground glass screen he fixed an opaque rod, placing a bright lamp and a candle at such distances from the rod that the shadows thrown by each light upon the screen appeared equally bright. Measuring the distance of each light from the shadows cast, he found the lamp to be four times as far away as the candle, from which, by the law of inverse squares, he perceived that the lamp was twice as bright as the candle.

Some fifty years later another light-measuring instrument was produced by the famous chemist Robert Wilhelm Bunsen. This admirably simple device consisted of a sheet of white paper with a grease spot on it. The ex-

periment may easily be made by any one. If the paper is equally illuminated from both sides the grease spot will be hardly visible, but if the light upon one side is made ever so little brighter than upon the other, the spot will at once appear on the darker side brighter (and on the brighter side darker) than the rest of the paper. The obvious reason of this is that the matt surface of the white paper reflects back more and transmits less of the light which falls upon it than does the part covered with a film of grease. If now a standard light be placed on one side

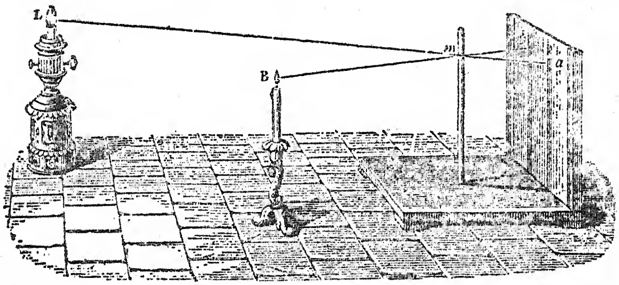


Fig. 13 —SIMPLE MODE OF MEASURING INTENSITY OF LIGHT.

of this paper, any other light whose "candle-power" is to be determined may be shifted back on the other side until the grease spot is no longer visible, when by measuring the distances of the two lights from the paper screen the relative intensity may easily be determined.

Incandescent electric lamps, arc lights and in fact all common illuminants are measured in candle power. One British standard candle power is the rate at which light is emitted by the flame of a sperm candle weighing $^1/_6$ of a pound and burning 120 grains per hour. The amount of light from such a source, however, has been shown to vary as much as 20 per cent., hence the standard is somewhat unsatisfactory. Ordinary electric glow lamps are equivalent to 16 standard candles and are therefore called

16 c.p. (candle-power) lamps. Other varieties of photometer ("light-measurers") have subsequently been invented, one of which, Wheatstone's, produces very beautiful luminous effects.

Similar in many ways to the measurement of the light of the sun is the accurate estimation of solar heat. In 1883 Samuel Pierpont Langley invented the bolometer, briefly described as an exquisitely delicate thermopile. Langley's invention was a part of his careful and elaborate preparation for that remarkable trip to the (then almost unknown) summit of Mount Whitney, in southern California, where the summits of the Sierra Nevada, rising precipitously in the dry air to a height of nearly fifteen thousand feet over the Mojave Desert to the eastward, furnished a suitable location for the study of the influence of the earth's atmosphere upon the radiations from the sun. "I spent nearly a year," says Langley, "before ascending the mountain in inventing and perfecting the new instrument which I have called the 'bolometer,' or 'ray-measurer.' The principle on which it is founded is the same as that employed by my late lamented friend, Sir William Siemens, for measuring temperatures at the bottom of the sea, which is that a smaller electric current flows through a warm wire than a cold one.

"One great difficulty was to make the conducting wire very thin and yet continuous, and for this purpose almost endless experiments were made, among other substances pure gold having been obtained by chemical means in a plate so thin that it transmitted a sea-green light through the solid substance of the metal. This proving unsuitable, I learned that iron had been rolled of extraordinary thinness in a contest of skill between some English and American iron-masters; and, procuring some, I found that fifteen thousand of the iron plates they had rolled, laid one on the other, would make but one English inch. Out of this the first bolometers were made. The iron is now replaced by platinum, in wires, or rather tapes, from a two-thou-

sandth to a twenty-thousandth of an inch thick, all but invisible, being far finer than a human hair. This thread acts as tho sensitive, like a nerve laid bare to every indication of heat and cold. It is, then, a sort of sentient thing; what the eye sees as light it feels as heat, and what the eye sees as a narrow band of darkness (the Frauenhofer line) this feels as a narrow belt of cold; so that, when moved parallel to itself and the Frauenhofer lines down the spectrum, it registers their presence."

Langley's fascinating story of his experimental trip to Mount Whitney, told in the records of the Royal Institution, is full of thrilling imaginative touches. A few lines may serve to show something of the immense difficulties which he had to overcome in getting his results. He writes: "We commenced our slow toil northward with a thermometer at 110° in the shade, if any shade there be in the shadeless desert, which seems to be chiefly inhabited by rattlesnakes of an ashen gray color and a peculiarly venomous bite. There is no water, save at the rarest intervals, and the soil at a distance seems as tho strewed with sheets of salt, which aids the delusive show of the mirage.

"At last, after a seemingly interminable journey, we pitched our tents and fell to work (for you remember we must have two stations, a low and a high one, to compare the results); and here we labored three weeks in almost intolerable heat, the instruments having to be constantly swept clear of the red desert dust which the hot wind brought. Close by these tents a thermometer covered by a single sheet of glass and surrounded by wool rose to 237° in the sun, and sometimes in the tent, which was darkened for the study of separate rays, the heat was absolutely beyond human endurance.

"Finally our apparatus was taken apart and packed in small pieces on the backs of mules, who were to carry it by a ten days' journey through the mountains to the other side of the rocky wall, which, tho only ten or twelve miles

distant, arose miles above our heads; and, leaving these mule-trains to go with the escort by this longer route, I started with a guide by a nearer way to those white gleams in the upper skies that had daily tantalized us below in the desert with suggestions of delicious, unattainable cold. That desert sun had tanned our faces to a leather-like brown, and the change to the cooler air as we ascended was at first delightful. But the colder it grew the more the sun burnt the skin—quite literally burnt, I may say; so that by the end of the third day my face and hands, case-hardened, as I thought, in the desert, began to look as if they had been seared with red-hot irons, here in the cold, where the thermometer had fallen to freezing at night; and still, as we ascended, the paradoxical effect increased. The colder it grew about us the hotter the sun blazed above. It almost seemed as tho sunbeams up here were different things, and contained something which the air filters out before they reach us in our customary abodes. Radiation here is increased by the absence of water-vapor, too; and, on the whole, this intimate personal experience fell in almost too well with our anticipations that the air is an even more elaborate trap to catch the sunbeams than had been surmised, and that this effect of selective absorption and radiation was intimately connected with that change of the primal energies and primal color of the sun which we had climbed toward it to study.

"We suffered from cold (the ice forming three inches deep in the tents at night) and from mountain sickness, but we were too busy to pay much attention to bodily comfort and worked with desperate energy to utilize the remaining autumn days, which were all too short. Here, as below, the sunlight entered a darkened tent and was spread into a spectrum, which was explored throughout by the bolometer, measuring on the same separate rays which we had studied below in the desert, all of which were different up here, all having grown stronger, but in very different proportions."

The delicately constructed bolometer of Langley has been brought in comparatively recent years to very high perfection so as to record a change of temperature of .0000001 of a degree Centigrade. Prof. C. B. Boys in 1888 constructed a similar instrument capable of indicating so minute quantities of radiant heat that in the absence of atmospheric absorption the heat radiated from a candle two miles away would be distinctly registered. A still more perfect instrument lately completed in America similar to the radiometer of Dr. Crookes reached a marvelous degree of sensitiveness to radiant energy.

Experiments were made on the heat of a candle situated 2,000 feet from the concave mirror which focused its rays upon the instrument. The feeble radiations of the candle at this great distance sufficed to turn the indicator through nearly a hundred scale divisions, and even the face of an observer when placed in the position before occupied by the candle produced a deflection of 25 scale divisions. As a tenth of a single scale division could readily be observed, it will be seen, to speak figuratively, that with this radiometer one might note the approach of a friend while yet some miles distant, merely by the glow of his countenance.

CHAPTER VI

REFLECTION AND REFRACTION

A STRANGE phenomenon of light which long puzzled the scientific world was that of polarization, or two-sidedness. A crystal of tourmaline held between the eye and a light source will appear transparent. A second crystal placed in front of it will also allow the light to pass as long as the two crystals are held lengthwise. If one of them be turned at a right angle to the other the light is cut off. The explanation of this was a hard nut for Young to crack. He cracked it thus: "It is possible," he wrote in a letter to a friend, "to explain in this (undulatory) theory a transverse vibration propagated in the direction of the radius and with equal velocity, the motions of the particles being in a certain constant direction with respect to that radius transverse to the ray; and this is Polarization."

Thus Young explained that what happened in the progress of a light ray is the same thing as that which happens in the progress of a water wave; a stick of wood may be seen to rise and fall with the waves, but it does not advance with them, for the vibration is transverse to the direction of propagation. The apparent motion of the water in a wave is a forward motion; the actual motion is up and down. So is it with light. The analogy may be carried further, for when the wave approaches the shore, the lower part of it is arrested and the upper part is still carried forward by the impulse from behind. The result

is that the wave now takes a downward as well as a forward motion, and this effect becoming more and more pronounced the top of the wave curls completely over the water below and crashes as a breaker on the shore.

In light this change of direction also takes place whenever the light wave passes from air to a denser medium, such as water. If a ray of light strike the water at an angle, the lower part of the wave being arrested at the surface of the water, the ray bends downward into the water. A "normal" or perpendicular to the surface of the water would therefore form a larger angle with the ray in the air than in the water. The ray is said to be bent toward the normal in passing from a rare to a denser medium. Imagine the same ray to be shot back again, and it will obviously be bent from the normal as it leaves the water. It is evident from the water-wave analogy that the more the wave is stopped at the surface of the new medium the greater will be the bending.

In a substance like diamond, where the light travels less than half as fast as in air, the bending is very great, and the colors of which the white light is composed are much scattered and broken. Hence appear the magnificent lights in the diamond. In crown glass, where the wave travels two-thirds as fast as in air, there is less stoppage and consequently less refraction of the ray. In water, as has been remarked, the speed is three-fourths of the speed in air, hence the bending is still less.

Owing to this bending downward of a ray of light as it enters the water, it is evident that an observant trout will sight a fisherman some seconds before the latter sees the trout, and in the same way the setting sun will be visible to a fish in the water as shining apparently some degrees above the horizon. The effects of refraction are interesting, sometimes startling. It has been noted above that a ray of light passing from water into air suffers a bending away from the normal to the surface. That is, it tends to lie down and run along the surface. This tendency is more

marked as the angle of incidence increases. When the ray of light strikes the under surface of the water at a long angle it does not pass into the air, but runs along the surface of the water. Increase the angle ever so slightly, and the ray is actually bent down again through the water, affording the striking phenomenon of total reflection.

A familiar example of total reflection is found in the mirage. This reflection may take place whenever a ray of light passes from one layer of air to another of different density. The image of an inverted ship is observed commonly enough at sea before the ship itself comes over the horizon. The images of distant shores may be seen in like manner. The rays of light from the ship pass upward and reach some stratum of air which is warmer and consequently rarer than the air above the water immediately surrounding the vessel. From this rarer medium the image is bent down by total reflection and projected to some distant point. In the sandy plains of Egypt and other hot countries a similar phenomenon is due to similar causes. In this case, however, the image formed is reflected from a cooler stratum of air than that immediately above the burning sand of the desert. The inverted picture of trees thus formed in the sky is precisely analogous to the reflection of trees on the shore of a still lake. The reflecting medium in both cases is denser than that surrounding the object.

As the amount of light varies inversely as the square of the distance from the source, so it also varies with the angle at which the light falls. If the rays are projected vertically upon a surface, the amount of light will be greater than that received when they reach the surface at an angle. Hence the amount of light, as well as the amount of heat, which reaches the polar regions is far less than that which falls upon the equator. The same amount of light is spread over a larger surface.

Anything like accurate measurement of the amount of light received upon an object must always take into ac-

count the light due to reflection—for every visible surface reflects; if it did not it would not be visible. The scattering of the rays which results from a rough surface is utilized in minimizing the glare from a too brilliant source of light, such as the incandescent mantle of the Welsbach gaslight or the dazzling core of the electric arc. Ground glass globes enclose the lights and diffuse the intense brightness by scattering the rays which pass through the roughened surface. The great difficulty from an economic standpoint, with this method of softening the radiated light, is that nearly one-half of the illuminating power is wasted in the resistance offered by the semi-opaque glass globe. Diffuse reflection takes place at all points of the roughened surface.

The famous Mirror Maze, composed of several mirrors at various angles and scores of panes of clear glass, is so confusing that even extreme watchfulness will not prevent the observer from running into a pane of glass, not being able to perceive it. The reflection of any object in a plane mirror is a virtual, not a real image. There is no actual image where the object appears to be, and the virtual image so formed will be exactly as far in the rear of the mirror as the object itself is in front of it. This would follow inevitably from the well-known Law of Reflection, which, so far back as the time of Archimedes, was well understood as a fundamental principle of all mirrors of every shape and description.

If two mirrors are placed so as to touch at right angles, a candle placed in the angle will show three images reflected, no matter how the observer stands. By making the angle of the mirrors continually smaller, more and more images will be brought into view. When the angle of the mirrors is 60 degrees (the angle of an equilateral triangle) five images will appear, and seven if the mirrors are inclined at an angle of 45 degrees. When the angle is made small enough so that the mirrors are almost parallel, the number of reflections become practically infinite.

marked as the angle of incidence increases. When the ray of light strikes the under surface of the water at a long angle it does not pass into the air, but runs along the surface of the water. Increase the angle ever so slightly, and the ray is actually bent down again through the water, affording the striking phenomenon of total reflection.

A familiar example of total reflection is found in the mirage. This reflection may take place whenever a ray of light passes from one layer of air to another of different density. The image of an inverted ship is observed commonly enough at sea before the ship itself comes over the horizon. The images of distant shores may be seen in like manner. The rays of light from the ship pass upward and reach some stratum of air which is warmer and consequently rarer than the air above the water immediately surrounding the vessel. From this rarer medium the image is bent down by total reflection and projected to some distant point. In the sandy plains of Egypt and other hot countries a similar phenomenon is due to similar causes. In this case, however, the image formed is reflected from a cooler stratum of air than that immediately above the burning sand of the desert. The inverted picture of trees thus formed in the sky is precisely analogous to the reflection of trees on the shore of a still lake. The reflecting medium in both cases is denser than that surrounding the object.

As the amount of light varies inversely as the square of the distance from the source, so it also varies with the angle at which the light falls. If the rays are projected vertically upon a surface, the amount of light will be greater than that received when they reach the surface at an angle. Hence the amount of light, as well as the amount of heat, which reaches the polar regions is far less than that which falls upon the equator. The same amount of light is spread over a larger surface.

Anything like accurate measurement of the amount of light received upon an object must always take into ac-

count the light due to reflection—for every visible surface reflects; if it did not it would not be visible. The scattering of the rays which results from a rough surface is utilized in minimizing the glare from a too brilliant source of light, such as the incandescent mantle of the Welsbach gaslight or the dazzling core of the electric arc. Ground glass globes enclose the lights and diffuse the intense brightness by scattering the rays which pass through the roughened surface. The great difficulty from an economic standpoint, with this method of softening the radiated light, is that nearly one-half of the illuminating power is wasted in the resistance offered by the semi-opaque glass globe. Diffuse reflection takes place at all points of the roughened surface.

The famous Mirror Maze, composed of several mirrors at various angles and scores of panes of clear glass, is so confusing that even extreme watchfulness will not prevent the observer from running into a pane of glass, not being able to perceive it. The reflection of any object in a plane mirror is a virtual, not a real image. There is no actual image where the object appears to be, and the virtual image so formed will be exactly as far in the rear of the mirror as the object itself is in front of it. This would follow inevitably from the well-known Law of Reflection, which, so far back as the time of Archimedes, was well understood as a fundamental principle of all mirrors of every shape and description.

If two mirrors are placed so as to touch at right angles, a candle placed in the angle will show three images reflected, no matter how the observer stands. By making the angle of the mirrors continually smaller, more and more images will be brought into view. When the angle of the mirrors is 60 degrees (the angle of an equilateral triangle) five images will appear, and seven if the mirrors are inclined at an angle of 45 degrees. When the angle is made small enough so that the mirrors are almost parallel, the number of reflections become practically infinite.

marked as the angle of incidence increases. When the ray of light strikes the under surface of the water at a long angle it does not pass into the air, but runs along the surface of the water. Increase the angle ever so slightly, and the ray is actually bent down again through the water, affording the striking phenomenon of total reflection.

A familiar example of total reflection is found in the mirage. This reflection may take place whenever a ray of light passes from one layer of air to another of different density. The image of an inverted ship is observed commonly enough at sea before the ship itself comes over the horizon. The images of distant shores may be seen in like manner. The rays of light from the ship pass upward and reach some stratum of air which is warmer and consequently rarer than the air above the water immediately surrounding the vessel. From this rarer medium the image is bent down by total reflection and projected to some distant point. In the sandy plains of Egypt and other hot countries a similar phenomenon is due to similar causes. In this case, however, the image formed is reflected from a cooler stratum of air than that immediately above the burning sand of the desert. The inverted picture of trees thus formed in the sky is precisely analogous to the reflection of trees on the shore of a still lake. The reflecting medium in both cases is denser than that surrounding the object.

As the amount of light varies inversely as the square of the distance from the source, so it also varies with the angle at which the light falls. If the rays are projected vertically upon a surface, the amount of light will be greater than that received when they reach the surface at an angle. Hence the amount of light, as well as the amount of heat, which reaches the polar regions is far less than that which falls upon the equator. The same amount of light is spread over a larger surface.

Anything like accurate measurement of the amount of light received upon an object must always take into ac-

count the light due to reflection—for every visible surface reflects; if it did not it would not be visible. The scattering of the rays which results from a rough surface is utilized in minimizing the glare from a too brilliant source of light, such as the incandescent mantle of the Welsbach gaslight or the dazzling core of the electric arc. Ground glass globes enclose the lights and diffuse the intense brightness by scattering the rays which pass through the roughened surface. The great difficulty from an economic standpoint, with this method of softening the radiated light, is that nearly one-half of the illuminating power is wasted in the resistance offered by the semi-opaque glass globe. Diffuse reflection takes place at all points of the roughened surface.

The famous Mirror Maze, composed of several mirrors at various angles and scores of panes of clear glass, is so confusing that even extreme watchfulness will not prevent the observer from running into a pane of glass, not being able to perceive it. The reflection of any object in a plane mirror is a virtual, not a real image. There is no actual image where the object appears to be, and the virtual image so formed will be exactly as far in the rear of the mirror as the object itself is in front of it. This would follow inevitably from the well-known Law of Reflection, which, so far back as the time of Archimedes, was well understood as a fundamental principle of all mirrors of every shape and description.

If two mirrors are placed so as to touch at right angles, a candle placed in the angle will show three images reflected, no matter how the observer stands. By making the angle of the mirrors continually smaller, more and more images will be brought into view. When the angle of the mirrors is 60 degrees (the angle of an equilateral triangle) five images will appear, and seven if the mirrors are inclined at an angle of 45 degrees. When the angle is made small enough so that the mirrors are almost parallel, the number of reflections become practically infinite.

An interesting and striking fact with regard to these multiple images is that every image so formed, as well as the luminous object itself, will lie on the circumference of a circle of which the juncture of the mirrors is the exact center. This, again, may readily be shown to be an obvious result of the familiar Law of Reflection.

Sir David Brewster, of the University of Edinboro, invented early in the nineteenth century a reflecting instrument through which he became better known than by any of his more elaborate contributions to science. The kaleidoscope, a simple little device to be had to-day in almost any toy shop, was constructed by him with three plane mirrors. These were made of equal width and length, and fitted into a tube closed at one end by a disk or plate of ground glass, behind which irregular bits of colored glass or porcelain were allowed to tumble and turn in any direction. The latter were held in place by another disk of clear glass. When viewed from a small aperture in the farther end of the tube these bits of colored glass showed by their multiple reflections in the three mirrors an amazing variety of beautiful symmetrical designs apparently without number or end. So great at one time was the demand for these kaleidoscopes that it was found impossible to supply it. A more complicated series of images of great diversity is made by placing six mirrors together so as to form a regular hexagon, each angle of which is exactly twice the angle of an equilateral triangle, or 120 degrees. This is the form in which mirrors have been combined to produce the remarkable vistas of crystal mazes, of which a noteworthy example has recently been constructed in Paris, wherein the turn of a lever transports the observer from a forest grove to the interior of a Hindu temple or the wonderful Arabian palace of Aladdin.

The image formed by a glass mirror is not reflected by the glass. Back of every such mirror will be found a thin layer of some metallic substance, which forms a

much better reflecting surface than the glass. A beam of light falling on the mirror will be partly reflected from the front surface of the glass, but mainly from the metallic hinder surface. Thus it becomes apparent why a mirror, especially a thick one, forms two or more distinct images of an object seen at an angle in the glass. A consideration of the law of Total Reflection will show how many such images may actually be formed, reflected back and forth from the two surfaces of the mirror, and growing rapidly dimmer, so that usually not more than one or two are plainly to be seen.

A certain astronomical observer, not many years ago, betrayed in this connection an unconscious vein of humor. By means of the reflections from a plate of clear glass he announced the discovery of a large satellite circling the planet Venus! On account of these repeated images in glass mirrors, they are usually replaced, in physical observatories, by metallic reflectors.

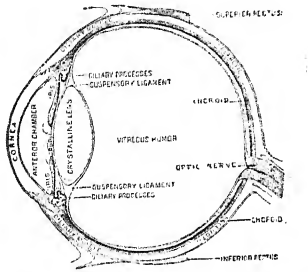
The great law of Reflection, that the Angle of the Incident Ray equals the Angle of the Reflected Ray, was found to hold true for all angles and all surfaces. The law applies with equal rigor to a plane mirror or to a reflecting surface of any other type, spherical, cylindrical, conical, concave or convex. Nearly a thousand years ago the famous Image Problem of the Arab Al Hazen, to which reference has already been made, was formulated, calling for a proof of the images formed in plane, spherical and conical mirrors. The spreading of the rays of light will obviously change the appearance of the image formed in any convex reflecting surface, while the opposite effect will produce an opposite change in the image formed in a concave reflector.

The image formed by looking in the bowl of an ordinary spoon is seen to be inverted. No matter which way the spoon is held, sidewise or upside down, this will always be found true—unless the spoon is large and brought very close to the face. Looking at the back of the spoon,

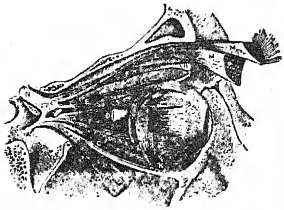
however, the image is seen to be erect, no matter how near or how far away the spoon is held. The reason is easily seen. Every ray of light from an object must glance off from the polished metallic surface at the same angle as that at which it strikes. In a concave surface, such as the hollow of a spoon, these rays must evidently meet somewhere and then cross. Evidently the image formed after they cross will be upside down and left side right. Such an image is real, for it is actually formed where it appears to be, and in this respect differs from the images formed in plane or convex mirrors, which apparently exist where experience proves they cannot exist, viz., behind the reflector. If the reflection in a concave surface is made by an object held close to the mirror, it will form an enlarged erect virtual image; the rays of light do not pass through the focus, or crossing point of the mirror, hence there is no inversion, and the image, but for the enlargement, is exactly like that formed in a plane mirror. It appears behind the surface.

Parabolic mirrors which have come into such general use for powerful lighting purposes—as, for example, in the headlights of automobiles and locomotives—show but a slight modification of the concave spherical mirror. The change, tho slight, is important, for all the rays of light from the lamp within the reflector now strike the side walls at such an angle that they pass out in parallel lines; therefore, except for the light lost in absorption, at the metallic surface every bit of illumination is centered in the one direction. The illuminating power of these reflectors, when furnished with a brilliant light, is enormous. The parabolic mirror is said to have been known since the time of Archimedes.

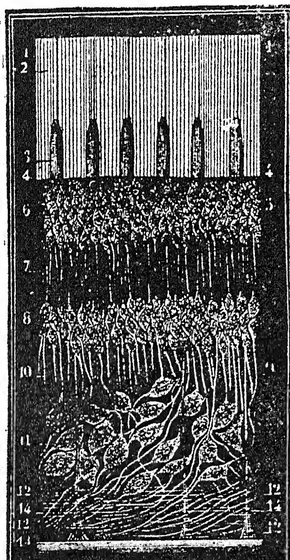
The convex surface of the back of an ordinary spoon forms, as has been said, an erect image, which appears reduced and at a distance of several inches behind the spoon. Withdraw the spoon slowly, and the image continues to recede and diminish, until at a certain point the



CROSS SECTION OF GLOBE OF EYE.

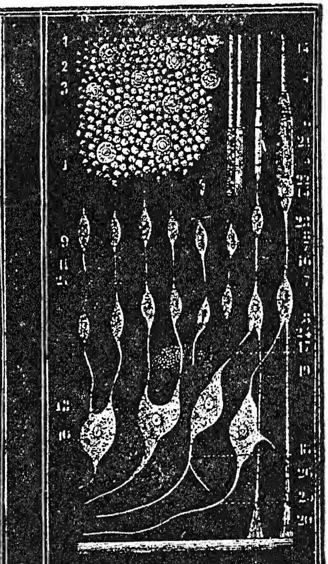


MUSCLES OF EYE WHICH DIRECT MOVEMENTS.



VERTICAL SECTION OF RETINA. (After H. Müller.)

1., layer of rods and cones; 2., rods; 3., cones; 4., 5., 6., external granule layer; 7., internal granule layer; 9., 10., finely granular gray layer; 11., layer of nerve-cells; 12., 14., fibers of optic nerve; 13., membrana limitans.



CONNECTION OF RODS AND CONES OF RETINA WITH NERVOUS ELEMENTS. (After Sappey.)

1., 2., 3., rods and cones seen from in front; 4., 5., 6., side view.

diminution seems to stop and the image remains constant no matter how far away the spoon is moved. Here, as before, a converging point of the rays of light will be found, this time behind the mirror; but there will be no crossing, for the rays will exactly meet and the image be reduced to a point only when the object has been removed to a distance theoretically infinite.

In general, it has been said of all real images that they are those formed by the reflected rays themselves, whereas virtual images are formed by their imaginary prolongations. The real image is always inverted and the virtual image erect. By analogy with the phenomena of images in convex and concave mirrors, the process of image formation through the ordinary convex lens will readily be understood. The process here, as has been shown, is one of refraction, not of reflection of light. But the bending of the rays to a focus on either side of the lens will determine, as before, the form of the image, whether erect or inverted. Images formed by refraction through a convex lens must in all cases when the object is outside the focus be real, since the figure is actually formed and may be shown on a screen exactly where it appears to be.

If the object is placed inside the focus of the lens—*i.e.*, between the focus and the lens itself—an enlarged virtual image will be seen. This is the case in ordinary reading glasses; the light rays from all extremities of the object (letters or what-not) under examination are twice refracted by the double convex surface of the lens, and the eye sees these points of the object along the line last traveled by the light. Hence the object appears greatly magnified—its extremities appearing to be much farther apart than in reality they are. The more convex the lens the greater is its magnifying power, but the greater, at the same time, the difficulty in using it without some correction of the spherical aberration which increases with the curvature of the lens. Double convex lenses, used as magnifying glasses, are frequently called simple

scopes, as distinguished from the powerful compound microscope, which by the aid of brilliant illumination produces an image many thousand times larger than the original. The focus of all convex lenses was seen to be the place where rays of light traveling straight to the lens are bent together by refraction and meet. There will evidently be two such foci formed, one on either side of every double convex lens. These are the so-called conjugate foci of the lens. In concave lenses there is no real

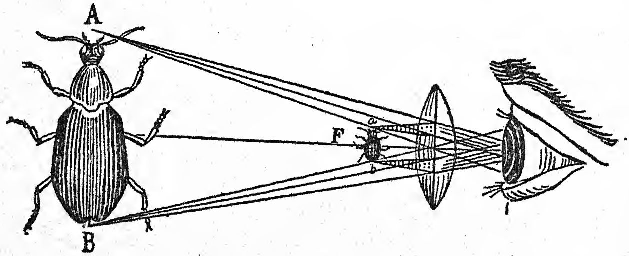


Fig. 14 —Angles of a Lens.

focus possible, since all rays will be refracted in a direction away from the perpendicular through the center of the lens. All images through such a lens will therefore be virtual images.

The earliest lenses were made in Europe of rock crystal, altho lenses of glass appaer to have been known to the Greeks. The lenses of Hans Lippersley, of Middleburg, the inventor of the binocular telescope, were made of rock crystal. (These small instruments, it is interesting to note, sold at that time (1608) for the large sum of 900 gulden.) Galileo's lenses, one of them concave the other convex, were made of glass. Sparing neither expense nor labor, he succeeded in constructing an instrument which magnified an object nearly a thousand times and brought it more than thirty times nearer. He went to Venice to

display his telescope. "Many noblemen and senators," says he, "altho of great age, mounted the steps of the highest church towers at Venice to watch the ships, which were visible through my glass two hours before they were seen entering the harbor."

In the early telescopes lenses were made with very great focal lengths—the beams converging in some cases at a distance of 10, 20, 30, 40 and in one instance of 123 feet from the center of the lens. These lenses were mounted on high poles, and being unprotected by a tube gave very inferior results. The purpose of these great clumsy objectives was the avoidance of the color dispersion which is always observable at the edges of a simple lens of pronounced curvature. Since the prism has shown that the blue rays of light are bent more than the red, they must come to a focus behind a lens a little sooner than the red rays. This is the explanation of the fact that so many common lenses, reading glasses, etc., make it appear that the objects behind them are surrounded with a colored halo. This is more noticeable in lenses of much curvature, for the difference in focus between the red rays and the blue is then emphasized.

Leonhard Euler suggested that lenses made out of two different materials of different refractive powers would probably cure this "chromatic aberration." He tried to produce such a lens, but failed. A London optician, John Dolland, taking up Euler's idea, began a series of tests in making lenses which were achromatic—*i.e.,* showing no color dispersion. Years of repeated failure in this direction were finally crowned with success, and Dolland produced a lens made of crown and flint glass which was perfectly free from color and entirely accurate. His accomplishment created a sensation throughout Europe and greatly facilitated from that time the growth of astronomy. Lenses began to increase in diameter and telescopes in size. Herschel, the discoverer of the two inmost moons of Saturn, added immense concave mirrors

to his telescopes whereby the light-gathering power of the instrument was vastly increased. At Parsonstown in Ireland was completed a gigantic reflecting telescope with a mirror 6 feet across and a tube 58 feet long and 7 feet in diameter, so that a certain ecclesiastic, Dean Peacock, once walked through it with uplifted umbrella.

The achromatic lenses which made possible these great telescopes were likewise instrumental in the development of microscopes, to which they were early applied. The first microscope was constructed in the beginning of the seventeenth century by Zacharias Johannides, a Dutch optician. The eyepieces of his microscope were made at first concave; subsequent improvements made both lenses convex.

Spectacles also were manufactured with achromatic lenses, greatly increasing their comfort and serviceability. The inventor of spectacles must rest his claim to this honor upon an inscription dated some three hundred years before the invention of achromatic lenses. Upon the tomb of Salvino Armato in Florence is carved below the bust of this nobleman the inscription:

Here lies
SALVINO ARMATO D'ARMATI,
of
FLORENCE,
INVENTOR OF SPECTACLES
May God pardon his sins
A.D. 1317.

In the tall lighthouses that to-day guard the coast of every civilized country is found the peculiar échelon or annular lens. To avoid the spherical aberration, and the loss of light inevitable in refractors of such magnitude as those of the lighthouse lights, these lenses are made in concentric rings of glass, which focus in one point, the outermost ring being some two feet in diameter. The light placed in this focus is not too widely distributed, and becomes brightly visible over a distance of more than

forty miles. Some conception of the power of these lenses may be had from the fact that when inverted and used to condense the solar rays, gold, platinum and quartz are melted in the intense heat, and less refractory substances, as lead, tin and zinc, are almost immediately reduced to a vapor.

Far more perfect than any previously produced were the glass lenses made in Munich by Joseph Frauenhofer. The talented son of a poor glazier, Frauenhofer combined a thoro practical skill with an unusual degree of theoretic insight. "By his invention of new and improved methods, machinery and measuring instruments for grinding and polishing lenses, by his having the superintendence, after 1811, also of the work in glass melting, enabling him to produce flint and crown glass in larger pieces, free of veins, but especially by his discovery of a method of computing accurately the forms of lenses, he has led practical optics into entirely new paths, and has raised the achromatic telescope to a perfection hitherto undreamed of." So writes Lommel in his preface to Frauenhofer's 'Gesammelte Schriften.'

Among the many other applications of the lens which have made a necessary place in present-day life, the camera deserves especial notice. Baptista Porta, a Neapolitan physician and contemporary of the great Gilbert, invented an instrument now familiar enough to every school boy of a practical turn of mind—the camera obscura. A simple box, light proof, and painted black within and without, received through a lens the image of external objects and reflected it from a sloping white paper screen on to a plate of ground glass in the top of the box. To imitate in the form of a fixed photograph the beautiful colored image thus thrown on the plate subsequent artists and scientists have sought in vain; the "color photography" thus far accomplished has been a complicated and difficult procedure, rewarded by only partial success.

to his telescopes whereby the light-gathering power of the instrument was vastly increased. At Parsonstown in Ireland was completed a gigantic reflecting telescope with a mirror 6 feet across and a tube 58 feet long and 7 feet in diameter, so that a certain ecclesiastic, Dean Peacock, once walked through it with uplifted umbrella.

The achromatic lenses which made possible these great telescopes were likewise instrumental in the development of microscopes, to which they were early applied. The first microscope was constructed in the beginning of the seventeenth century by Zacharias Johannides, a Dutch optician. The eyepieces of his microscope were made at first concave; subsequent improvements made both lenses convex.

Spectacles also were manufactured with achromatic lenses, greatly increasing their comfort and serviceability. The inventor of spectacles must rest his claim to this honor upon an inscription dated some three hundred years before the invention of achromatic lenses. Upon the tomb of Salvino Armato in Florence is carved below the bust of this nobleman the inscription:

Here lies
SALVINO ARMATO D'ARMATI,
of
FLORENCE,
INVENTOR OF SPECTACLES
May God pardon his sins
A.D. 1317.

In the tall lighthouses that to-day guard the coast of every civilized country is found the peculiar échelon or annular lens. To avoid the spherical aberration, and the loss of light inevitable in refractors of such magnitude as those of the lighthouse lights, these lenses are made in concentric rings of glass, which focus in one point, the outermost ring being some two feet in diameter. The light placed in this focus is not too widely distributed, and becomes brightly visible over a distance of more than

forty miles. Some conception of the power of these lenses may be had from the fact that when inverted and used to condense the solar rays, gold, platinum and quartz are melted in the intense heat, and less refractory substances, as lead, tin and zinc, are almost immediately reduced to a vapor.

Far more perfect than any previously produced were the glass lenses made in Munich by Joseph Frauenhofer. The talented son of a poor glazier, Frauenhofer combined a thoro practical skill with an unusual degree of theoretic insight. "By his invention of new and improved methods, machinery and measuring instruments for grinding and polishing lenses, by his having the superintendence, after 1811, also of the work in glass melting, enabling him to produce flint and crown glass in larger pieces, free of veins, but especially by his discovery of a method of computing accurately the forms of lenses, he has led practical optics into entirely new paths, and has raised the achromatic telescope to a perfection hitherto undreamed of." So writes Lommel in his preface to Frauenhofer's 'Gesammelte Schriften.'

Among the many other applications of the lens which have made a necessary place in present-day life, the camera deserves especial notice. Baptista Porta, a Neapolitan physician and contemporary of the great Gilbert, invented an instrument now familiar enough to every school boy of a practical turn of mind—the camera obscura. A simple box, light proof, and painted black within and without, received through a lens the image of external objects and reflected it from a sloping white paper screen on to a plate of ground glass in the top of the box. To imitate in the form of a fixed photograph the beautiful colored image thus thrown on the plate subsequent artists and scientists have sought in vain; the "color photography" thus far accomplished has been a complicated and difficult procedure, rewarded by only partial success.

The camera obscura may hardly be considered the antecedent of the photographic camera of to-day, which resembles the pin-hole camera in structure more nearly. Yet the essential principle of the modern camera was not different from that of the camera obscura. With an adjustable or focusing lens and the substitution of a sensitive film or plate for the former plate of ground glass, the transformation was accomplished. In modern days many people take photographs, and there is more or less familiarity with the nature of the chemical changes that are worked by the exposure to the light of the silver salts upon the "sensitive" plate. If exacting Reason, however, demand in this connection an explanation of why the change takes place, it must be answered in brief that the energy of the light ray probably effects a rapid alteration of the structure of the atoms of the silver salt employed, in much the same way as has been noted before in the different forms of copper and iron. When the velocity of waves of light is remembered, it becomes clear that a $^1/_{10}$ second exposure means that these atoms have been hammered thousands of times by light waves in that brief period.

The art of photography is of very recent development, depending of necessity upon a certain advance in the science of chemistry. Pictures on metal were produced in 1827 by Joseph Nicephore Niepce, whose assistant and successor in this work, Daguerre, has given his name to the improved metallic photographs which are still called, after him, daguerreotypes. These first efforts at a photograph were clumsy contrivances, requiring from five to seven minutes' exposure, during which the photographee must sit with iron face and rigid figure, immovable. The face of the sitter had also to be dusted with white powder, and the print, when completed, was faint, and in certain lights invisible, on account of the brilliant polish of the metallic surface upon which the print was made. Tinting the picture was commonly resorted to in the en-

deavor to make the result more life-like. From the slow and troublesome methods of the old daguerreotype to the magnificent black and white instantaneous carbon prints of to-day is a long stride.

It frequently happens in human history that after an invention has been made and perfected, the further progress of knowledge reveals the fact that the wonderful invention already existed in Nature in a state of development far more advanced. The old scoop dredge, tho it still has its special use, has been largely replaced by a huge iron hand like a man's hand; the phonograph is a clumsy imitation of the auricular nerve and tympanum of the human ear; the eye has been described as a camera with a self-adjusting shutter and focusing automatically. Without going too minutely into the physical structure of the eye, its essential parts may briefly be summed up.

Covering all the exposed front of the organ is a tough elastic membrane (cornea), which lets through the light, but protects the delicate mechanism immediately behind. This interior part it is which lends character and color to the eye, the iris or colored ring appearing of various hues—as ranging from a light gray-blue, which is largely destitute of the orange-brown coloring pigment, to a brown so deep as almost to seem black. "Helmholtz," writes Cajori in his history already referred to, "irreverently disclosed the fact that in blue eyes there is no real blue coloring matter whatever; the deepest blue is nothing but a turbid medium. The optic action is the same as in the case of smoke which appears blue on a dark background, tho the particles themselves are not blue; or in case of the sky, which, according to Newton, Stokes and Rayleigh, looks blue through the agency of extremely fine dust suspended in the air. This dust, when illuminated by sunlight, reflects a greater proportion of the shorter waves of bluish light and transmits a greater proportion of longer waves of reddish light."

The 'pupil' of the eye is the shutter, which, by the ex-

pansion or contraction of the iris, lets in more or less light to the sensitive film or 'retina' at the back of the organ. Close behind the pupil and its encircling iris the crystalline lens refracts incident light from objects near or remote, and by the aid of the enveloping 'ciliary' muscle may be so far contracted as to focus the vision with equal readiness upon a tiny shell in the hand or a mass of rocks on a far-distant mountain. Through the glassy liquid which fills all the remaining interior of the eye the light is transmitted to the retina, where a chemical change is constantly being effected upon the exposed film of this optical photographic camera, the optic nerves reporting to the brain at every moment the nature of these changes.

With all its beauty and delicate adjustment, however, the human eye has many imperfections. No voice has spoken of the physics of the eye with more authority than has the extraordinarily versatile and learned Helmholtz. To him the eye is indeed a crude instrument. The German physicist indicates its defects with considerable force. "A refracting surface which is imperfectly elliptical," he says, "an ill-centered telescope, does not give a single illuminated point as the image of a star, but according to the surface and arrangement of the refracting media, elliptic, circular, or linear images. Now the images of an illuminated point, as the human eye brings them to focus, are even more inaccurate: they are irregularly radiated. The reason of this lies in the construction of the crystalline lens, the fibers of which are arranged around six diverging axes, so that the rays which we see around stars and other distant lights are images of the radiated structure of our lens; and the universality of this optical defect is proved by any figure with diverging rays, being called 'star-shaped.' It is from the same cause that the moon, while her crescent is still narrow, appears to many persons double or threefold."

"Now, it is not too much to say," he remarks again, "that if an optician wanted to sell me an instrument which

had all these defects, I should think myself quite justified in blaming his carelessness in the strongest terms and giving him back his instrument."

The mechanical process of the eye has never, until comparatively recently, been understood. Helmholtz and others, basing their experiments upon the observations of Thomas Young, Louis Joseph Sanson and Max Lagenbeck, have explained the manner in which the eye focuses and the means employed to control the admission of light. The sense of color, however, is still a matter of controversy. The most acceptable theory of color sense is that promulgated by Young and developed by Helmholtz, based on the phenomenon of color blindness to the three shades which occupy respectively the ends and the center of the prismatic ribbon, viz., red, green and violet. Color blindness to red is common and to green not uncommon, while the inability to recognise violet is known. Young showed that the rotation of colored disks of red, green and violet produces the impression of gray. These, therefore, may be taken as the three primary colors, by combination of which all the intermediate colors may be produced.

CHAPTER VII

THE NATURE OF LIGHT

To THE phenomenon of total reflection was added in the very beginning of the nineteenth century another bit of evidence which the exponents of the corpuscular theory of light found difficult to explain away. This was the phenomenon of interference. Two plates of glass touching at one end and separated at the other by a fine hair will form between them a thin wedge of air. If a bright light is held near the plates they will be seen crossed with dark and bright bands. Thomas Young, a brilliant young English physicist, experimenting with these plates and studying the dark bands, stated in a famous paper on light that they were due to the interference of light waves from the two surfaces of the wedge of air included between the plates of glass. He showed how the waves of light from these two surfaces might be proved to meet at intervals and produce the appearance of darkness, just as two sound waves may be combined to produce silence.

This remarkable paper, by far the most valuable contribution to the study of optics since the time of Newton, attracted no favorable attention and was received with open scorn and contempt by the editor of the Edinboro Review. The young scientist is represented by this illustrious organ as deficient in "the powers of solid thinking" and his theories dismissed as "feeble lucubrations without any traces of learning, acuteness or ingenuity." John Tyndall, that great and fascinating Irish scientist, writes

of Young: "For twenty years this man of genius was quenched—hidden from the appreciative genius of his countrymen—deemed, in fact, a dreamer, through the vigorous sarcasm of a writer who had then possession of the public ear. To the celebrated Frenchmen, Fresnel and Arago, he was first indebted for the restitution of his rights." The soundness of Young's reasoning has been abundantly attested to by the verdict of later investigators, and the known fact of the "interference" of light is to-day held to be one of the compelling arguments in favor of light as a form of vibration.

Difficult of explanation as the fact of interference proved from a corpuscular basis, still more did prismatic dispersion prove itself an occasion of falling. Every one is familiar with the beautiful color effects obtainable with the aid of a triangular prism of glass, and has noted how a beam of "white" light may be spread out into a band of colors as the ray is bent through the prism. In this spreading out it is evident that some of the rays are bent more than others. Unless the corpuscles of light were infinite in variety, this would be simply inexplicable as a corpuscular phenomenon. The prism as an instrument of optical study found its first great master in Isaac Newton. The observation of its effects had been noted by the Roman philosopher Seneca, and in the period of the Renaissance the breaking up of white light into colors was discussed by Grimaldi, Descartes, Hooke and others. But it required the supreme genius of Newton to make clear the true idea of the dispersion of light. With rough appliances fashioned by his own hands he conducted his experiments. In his treatise on "Opticks' he quaintly remarks, "I procured me a triangular glass prisme, to try therewith the celebrated phenomena of colors. And in order thereto having darkened my chamber, and made a small hole in my window-shuts to let in a convenient quantity of the sun's light, I placed my prisme at his entrance, that it might be thereby refracted to the opposite wall."

He goes on to say how surprised he was to find that the ray of light, after passing through the prism, instead of being thrown upon the wall in the form of a round spot, was spread out into a beautiful colored ribbon, or spectrum, red at one end, yellow in the middle, and bluish green at the other end. "Comparing the length of this colored spectrum with its breadth," he continues, "I found it about five times greater—a disproportion so extravagant that it excited me to a more than ordinary curiosity of examining from whence it might proceed.

"Then I began to suspect, whether the rays after their trajection through the prism, did not move in curve lines, and according to their more or less curvity tend to divers parts of the wall. And it increased my suspicion, when I remembered that I had often seen a tennis ball struck with an oblique racket, describe such a curve line. For, a circular as well as a progressive motion being communicated to it by that stroke, its parts on that side, where the motions conspire, must press and beat the contiguous air more violently than on the other, and there excite a reluctancy and reaction of the air proportionably greater. And for the same reason, if the rays of light should possibly be globular bodies, and by their oblique passage out of the medium into another, acquire a circulating motion, they ought to feel the greater resistance from the ambient æther, on that side, where the motions conspire, and thence be continually bowed to the other. But notwithstanding this plausible ground of suspicion, when I came to examine it, I could observe no such curvity in them. And besides (which was enough for my purpose) I observed, that the difference betwixt the length of the image, and the diameter of the hole, through which the light was transmitted, was proportionable to their distance.

"The gradual removal of these suspicions at length led me to the experimentum crucis, which was this: I took two boards, and placed one of them close behind the prism at the window, so that the light might pass through a

small hole, made in it for the purpose, and fall on the other board, which I placed at about twelve feet distance, having first made a small hole in it also, for some of that incident light to pass through. Then, I placed another prism behind the second board." On turning the first prism about its axis, the image which fell on the second board was made to move up and down upon that board, so that all its parts could successively pass through the hole in that board, and fall upon the prism behind it. The places

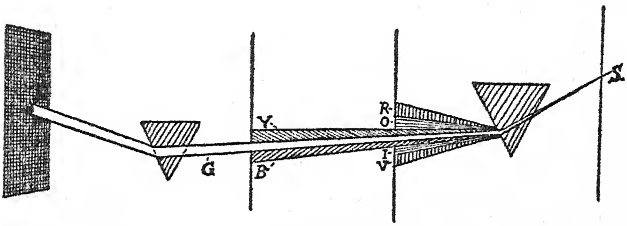


Fig. 15.—Experiment Showing Refraction and Division of Light Rays, Until Green Ray Will Not Subdivide Further.

where the light fell against the wall were noted. It was seen that the blue light, which was most refracted in the first prism, was also most refracted in the second prism, the red being least refracted in both prisms. "And so the true cause of the length of that image was detected to be no other than that light is not similar or homogeneal, but consists of difform rays, some of which are more refrangible than others."

No more complete or illuminating explanation of the nature of light through the agency of the prism has ever been given than this. Newton showed here the real reason of the dispersion, adducing the analogy of the rainbow, altho he clung through it all to the corpuscular theory, postulating the existence not only of the flying particles constituting light, but also of an ether—all the mechanism, in fact, needed for the wave theory, and more.

It was not until the beginning of the present century that this experiment of Newton's (repeated as it had been in the meantime by many philosophers) was found by Dr. Wollaston to possess certain peculiarities which defied all explanation. He found that, by substituting a slit in the shutter of the darkened room for the round hole which Newton had used, the spectrum was intersected by certain dark lines. This announcement, altho at the time it did not excite much attention, led to further experiments by different investigators, who, however, vainly endeavored to solve the meaning of these bands of darkness. It was observed by the great Munich optician that they never varied, but always occupied a certain fixed position in the spectrum; moreover, he succeeded in mapping them to the number of nearly six hundred, for which reason they have been identified with his name, as "Frauenhofer's lines."

It was one of the greatest contributions to science. Accidentally he discovered in the spectrum of a lamp the double line in the orange, now known as the sodium, line. He was endeavoring at the time to determine how the refraction through glass would take place for different colored lights. The observation of the sodium line was a chance incident of his experiments. In oil and tallow light, and in fact in all firelight, he saw this same bright, sharply defined double line "exactly in the same place and consequently very useful." Examining the spectrum of sunlight cast through a small telescope upon a prism, he remarked "an almost countless number of strong and feeble vertical lines which, however, were darker than the other parts of the spectrum, some appearing to be almost perfectly black." He also examined starlight with his primitive spectroscope and found many of the solar lines in the spectrum of the planet Venus. For nearly forty years the scientific world, absorbed in theories concerning the nature of light itself, or the newly announced atomic theory of Dalton and the laws of chemical combination and composition, failed to see the meaning and significance of this

discovery of Frauenhofer. The great astronomer J. F. W. Herschel, the electrician Wheatstone, William Henry Fox Talbot, Sir David Brewster and others remarked on various similar phenomena in spectral experimentation, but none succeeded in finding the clue to the mystery. Many famous men between 1850 and 1860 turned their attention to this riddle.

Herschel pointed out that metals, when rendered incandescent under the flame of the blowpipe, exhibited various tints. He further suggested that as the color thus shown was distinctive for each metal, it might be possible by these means to work out a new system of analysis.

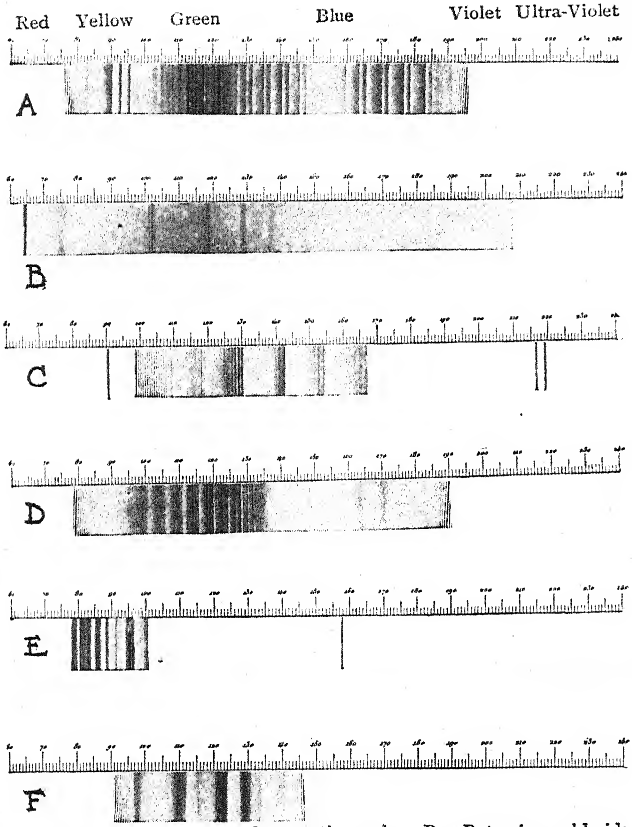
Bunsen and Kirchhoff in 1860 discovered that each metal when in an incandescent state exhibited through the prism certain distinctive brilliant lines. They also found that these brilliant lines were identical in position with many of Frauenhofer's dark lines; or to put it more clearly, each bright line given by a burning metal found its exact counterpart in a dark line on the solar spectrum. It thus became evident that there was some subtle connection between these brilliant lines and the dark bands which had puzzled observers for so many years. Having this clue, experiments were pushed on with renewed vigor, until, by happy chance, the vapors of the burning metals were examined through the agency of the electric light. That is to say, the light from the electric lamp was permitted to shine through the vapor of the burning metal under examination, forming, so to speak, a background for the expected lines. It was now seen that what before were bright bands on a dark ground were now dark bands on a bright ground. This discovery of the reversal of the lines peculiar to a burning metal, when such metal was examined in the form of vapor, led to the enunciation of the great principle that "vapors of metals at a lower temperature absorb exactly those rays which they emit at a higher."

To make this important fact more clear, suppose that

upon the red-hot cinders in an ordinary fire-grate is thrown a handful of saltpeter, also called nitrate of potash or more commonly niter. On looking through the spectroscope at the dazzling molten mass thus produced (instead of the colored ribbons which the sunlight gives) all is black, with the exception of a brilliant violet line at the one end of the spectrum and an equally brilliant red line at the other end. This is the spectrum peculiar to potassium; so that, if not previously aware of the presence of that metal, and if requested to name the source of the flame produced, the spectroscope would have enabled such answer without difficulty. Now suppose this burning saltpeter to be again examined under altered conditions. Place the red-hot cinders in a shovel and remove them to the open air, throwing upon them a fresh supply of the niter. If the vapor now be examined while the sunlight forms a background to it, it will be seen that the two bright colored lines have given place to dark ones. This experiment will prove the truth of Kirchhoff's law so far as potassium is concerned, for the molten mass first gave the bright lines, and afterward by examining the cooler vapor it was evident that they were transformed to bands of darkness; in other words they were absorbed.

The simple glass prism as used by Newton, altho it is the parent of the modern spectroscope, bears very little resemblance to its gifted successor. The complicated and costly instrument now used consists of a train of several prisms, through which the ray of light under examination can be passed by reflection more than once. By these means greater dispersion is gained; that is to say, the resulting spectrum is longer, and consequently far easier of examination.

Since the middle of the nineteenth century the analytical eye of this wonderful instrument has looked into the material universe and aided the chemist to the discovery of elements previously unsuspected and unknown. It has shown the composition of sun and stars, by the correspon-



SPECTRA: A., electric spark, negative pole; B., Potassium chloride, vaporized; C., aluminum; D., chloride of gold, vaporized; E., Strontium chloride, vaporized; F., phosphoretted hydrogen.

dence of their spectra with those of terrestrial matter, to be in general identical with that of the earth. Nor are its services to be measured merely in qualitative units, for, in examining incandescent bodies, by a careful study of the absorption lines a very exact estimate of the 'quantity' present can be arrived at. This method of analysis is so delicate that in experiments carried on at the mint a difference of one ten-thousandth part in an alloy has been recognised. Neither must it be supposed that the services of the spectroscope are confined to metals, for nearly all colored matter can also be subjected to its scrutiny. Even the most minute substances, when examined by the microscope in conjunction with the prism, show a particular spectrum by which they can always be identified.

While the spectroscope succeeded in proving that a certain yellow flame was the flame of sodium and a certain reddish flame was that of calcium, it did not show why the flame of one kind of substance should be brighter than another. The flame of burning wood, for instance, is less bright, generally speaking, than that of a burning kerosene lamp; the flame of phosphorus burning in oxygen is dazzling in its brilliancy; a ribbon of the metal magnesium (commonly used as a powder in flashlight photographs) burns in ordinary air with an intensely brilliant white light. The brightness of these flames cannot be due wholly to temperature, as has often been maintained, for there may be a solid such as iron or carbon burning in oxygen at a high temperature, with brilliant incandescence, or glowing, but without flame, while on the other hand the lambent flame of boric methide or of camphor shows that flame may exist without a high temperature. A piece of burning camphor, in fact, may easily be held in the unprotected palm by changing it from hand to hand—a trick sometimes resorted to by stage jugglers. Again, the ordinary Bunsen burner found in every chemical laboratory will produce, by adjusting the air supply, either a yellow, luminous flame of relatively low temperature, or a

much hotter, non-luminous flame, whereas the temperature in the exceedingly brilliant electric arc is extreme, reaching in the electric furnace as high as 3,000 degrees Centigrade.

The real nature of flame was long a matter of conjecture. The "phlogiston" (fire-substance) of the eighteenth century, in fulfilment of the hope expressed by that erratic genius, Count Rumford, is to-day interred, it is true, in the same tomb with "caloric" (heat-substance). But the death of phlogiston did not bring with it the explanation of the luminosity of flame. Sir Humphrey Davy—inventor of the Davy Safety Lamp—regarded the luminosity as due to the incandescence of solid particles suspended in the flame, and this theory, until about the middle of the nineteenth century, went unchallenged. The presence of solid particles, either in the flame itself or in immediate contact with the burning gas, was held to be essential.

There is no doubt that the introduction of solid particles in a fine state of division into a flame of feeble luminosity will usually impart to it a considerable degree of brilliancy by the incandescence of the solid particles, or perhaps in some cases by reflection of the light from their many surfaces, and it is usual to refer to the black deposit which is formed upon a glass rod or similar body, when held in the flame of a candle or gas, as a proof that such flames contain solid particles.

Nevertheless luminous effects have been produced where the solid particle hypothesis could not account for them, such, for example, as the luminosity of the flame of hydrogen burning in oxygen under pressure; moreover, in many of the brightest flames the temperature is such that fuliginous matter could not exist in them. In many cases it seemed, therefore, to be a more satisfactory explanation, that the luminosity of flames depends on the existence of a comparatively high temperature and on the presence of gases or vapors of considerable density.

The effect of high temperature is seen in the greater brightness of the flames of sulphur, phosphorus, and, indeed, all substances when burnt in pure oxygen, as compared with the result of their combustion in air. Direct evidence of the effect of high temperature is also afforded by the combustion of phosphorus in chlorine, for while at ordinary temperatures only a feeble light is produced by this combustion, strongly heated phosphorus vapor burns in hot chlorine with a dazzling white light.

A comparison of the relative densities of gases and vapors shows that the brightest flames in general are those which contain the densest vapors.

Hydrogen burning in chlorine produces a vapor more than twice as heavy as that resulting from its combustion in oxygen, and the light produced in the former case is stronger than in the latter. Carbon and sulphur burning in oxygen produce vapors of still greater density, and their combustion gives a still brighter light. Phosphorus, also, which has a very dense vapor, and yields, in burning, a product of great vapor density, burns in oxygen with a brilliancy almost blinding.

The luminosity of a flame is increased by compressing around it the surrounding gaseous atmosphere, and it is diminished by rarefying it. Thus, mixtures of hydrogen and carbonic oxide with oxygen emit but little light when they are burnt or exploded in free air, but exhibit intense luminosity when exploded in closed vessels so as to prevent expansion of the gases at the moment of combustion.

The density, then, of the gases formed in combustion, and the temperature at which combustion takes place, were thus held by some physicists, notably E. Frankland, to be the sole determining factors in the brilliancy of a flame. As for the particles of solid matter, it is known that while in some instances they may increase the luminosity, in other cases they produce the opposite effect, rendering the flame less bright. All these known facts were thought during the latter half of the nineteenth cen-

tury completely to have disposed of the solid particle idea in the brightness of flames. As a matter of fact, it is evident that the "dense vapor" theory advocated by E. Frankland and others, while it adds much interesting information to what already is known of the nature of flame, does not in the least disprove the fact that a flame is bright when it contains particles of solid glowing carbon, and it is not luminous when it does not.

Such brilliant and thorough investigators as Heumann, Burch, Smithells, Techla, and especially Vivian B. Lewes, established the fact toward the end of the century that in the burning of ordinary illuminating gas that remarkable illuminant acetylene is first formed and subsequently decomposed. Lewes' careful experimentation showed that in the dark part of the flame there occurs a transformation of gases, and that at the point where luminosity just begins seventy to eighty per cent. of the compounds formed is acetylene, and this in a gas flame in which less than one per cent. of acetylene is originally present. Immediately above this point the increasing heat of the flame breaks up the acetylene gas into its two constituents, carbon and hydrogen. The hydrogen burns in contact with the oxygen of the air. The carbon is heated to incandesce by the combined influence of the burning hydrogen and the so-called "latent heat" of the chemical separation—hence the flame.

The real nature of flame is even to-day very commonly misapprehended. A popular idea exists that wood burns. Wood, strictly speaking, does not any more burn in air than it floats in water. The flames seen burning at the surface of a wood fire are due to the combustion of volatilized solid material, and their luminosity is generally conceded to-day to be due, as above shown, to the presence of finely divided particles of glowing carbon. Dr. Percy has accurately defined flame thus: "Ordinary flame is gas or vapor of which the surface, in contact with atmospheric air, is burning with the emission of light." This defini-

tion leaves little to be desired, for it very properly directs attention to the gas or vapor necessary to a flame, as well as to the fact that the flame itself is hollow.

Dr. Robert Montgomery Bird has summed up the essential teachings of modern study of flame briefly as follows:

When the hydrocarbon gas leaves the jet at which it is burned those portions which come in contact with the air are consumed and form a wall of flame, which surrounds the issuing gases. The unburnt gas in its passage through the lower heated area undergoes a number of chemical changes, brought about by the heat radiated from the flame walls; the principal change being the conversion of hydrocarbons into acetylene, hydrogen and methane. The temperature of the flame rapidly increases with the distance from the jet, and reaches a point at which it is high enough to decompose acetylene into carbon and hydrogen with a rapidity almost that of an explosion. The latent heat so suddenly set free is localized by the proximity of carbon particles, which by absorbing it become incandescent and emit the larger part of the light given out by the flame; altho the heat of combustion causes them to glow somewhat until they come into contact with oxygen and are consumed. This external heating gives rise to little of the light.

There have been opponents to this theory of the cause of luminosity—as there are, fortunately, of all theories—but the evidence is so strong and covers so many points, and so many investigators have confirmed one part or another of the work, that it has been generally accepted as a true statement of the facts with which it deals.

Visible light, as Frauenhofer long since pointed out, reaches the eye in vibrations numbering from 4,000 to 7,000 billion per second. No other vibrations are useful to us for seeing purposes, for no others have any effect upon the retina of the eye. The analysis of the apparently white light of the sun and the combining of the spectral

colors so formed to reproduce white light dates back to the time of Newton. Frauenhofer, however, devised a means of studying the solar spectrum without a prism. On plates of glass he ruled very fine parallel lines very close together, making the first grating. The beautiful iridescence of such substances as mother of pearl has been shown by the simple microscope to be due to a multitude of fine lines in the surface, the refracting edges of which disperse the prismatic colors like any true prism. Such a surface was the grating of Frauenhofer, and the great advantage of this instrument over the prism lay in the fact that the lower part of the spectrum where the red rays occur was very much spread out, whereas the simple prism dispersed the red end of the spectrum so little that examination of its characteristics was rendered difficult. Frauenhofer also experimented successfully with gratings made of very fine wire, .04 to .6 mm. (.002 to .03 inch) in thickness.

By the aid of similar gratings, John William Draper, of New York, not only confirmed the measurements of the light waves which Frauenhofer had made, but determined the temperature (525° C.) at which all solid and liquid substances become incandescent and glow with a red heat. He proved also that below this red heat invisible rays are emitted whose vibration lengths may be measured. Lewis Morris Rutherford, whose magnificent work in radioactivity has rendered him justly famous, produced other and better gratings made of thin sheets of metal, and Henry A. Rowland, of Johns Hopkins University, within very recent years ruled gratings so fine that they contained more than 100,000 lines to the inch—from fifty to a hundred in the width of a fine human hair—gratings which have never been surpassed. With the aid of these wonderfully fine gratings Rowland has prepared large photographic maps of the solar spectrum and prepared a system of standard wave lengths now universally adopted. The wave length of every line in the solar spectrum has been measured through this means, and there are few of

the common terrestrial elements which have not now been identified in the atmosphere of the sun.

The discovery of the invisible rays below the red of the solar spectrum dates back to Sir William Herschel, who in 1800 determined their existence by means of a thermometer. He noticed that the thermometer rose regularly when it was moved from the violet toward the red end of the spectrum, and it occurred to him to try the region beyond the extremes of the visible colors. To his delight he found a regular series of radiations below the red. "It is sometimes of great use in natural philosophy," the great astronomer observed, "to doubt of things that are commonly taken for granted, especially as the means of resolving any doubt, when once it is entertained, are often within our reach."

"This discovery," says Thomas Young in his 'Lectures' of 1807, "must be allowed to be one of the greatest that has been made since the days of Newton." Yet the majority of physicists failed for more than half a century to see the importance of this discovery of Herschel. It was only a few years after the discovery by Herschel of infra-red radiation from the sun that Johann Wilhelm Ritter and Wollaston proved the existence of dark chemical rays in the ultra-violet region of the spectrum. Macedonio Melloni, the inventor with Leopoldi Nobili of the thermopile, was the first to arrive at a thoro realization of the identity of radiant heat and light. "Light," said he, "is merely a series of calorific indications sensible to the organs of sight, or vice versa, the radiations of obscure heat are veritable invisible radiations of light." He argued that where there is light of any sort there must be some heat, and moonlight ought to show some heat effects. He experimented, at first unsuccessfully, in this direction, but finally with a lens more than three feet in diameter succeeded in getting feeble indications of heat from the rays of the moon. The thermopile which he used was a simple instrument based on the well-known principle that a cold

wire is, in general, a better conductor of electricity than a warm wire. Hence any simple galvanometer or other current-measuring apparatus showed by a deflection of the needle when any part of the electric conductor was heated.

The measurements of radiant heat made by Melloni in solids and liquids were paralleled by the investigations of Tyndall upon the diathermancy of gases. Tyndall possessed extraordinary powers of popularizing difficult scientific subjects. His first great lecture, delivered in 1853 in England, took his audience by storm. He came to America and delivered in 1872 and 1873 several lectures on light which were enthusiastically received. His famous "Belfast Address" brought upon the brilliant Irishman the charge of "infidelity," for he was as independent in thought as outspoken in expression and held ever to the principle that Truth has nothing to fear from its enemies.

Tyndall pointed out (as had Melloni before him) an error of wide prevalence concerning the influence of color and absorption. Benjamin Franklin records of himself that having placed patches of different-colored cloth of the same weight upon snow and allowed the sun to shine upon them, he found that they absorbed the solar rays to different degrees and sank to different depths in the snow. He concluded from this experiment that dark colors were the best absorbers and light colors the worst. For the visible rays of the sun this conclusion is in general true, but the solar rays consists of radiations running far outside the visible spectrum, about seven times the length of the solar spectrum having been detected in the infra-red radiations, and perhaps twice as much as is visible in the invisible ultra-violet.

The visible spectrum of "white" light has been shown by recent measurements to be only about one-tenth of the actual measurable solar spectrum. In the invisible region of the spectrum effects are often observed which are the exact opposite of those seen in the prismatic spectrum. Tyndall proved this in a clever manner. He coated the

bulb of a delicate mercury thermometer with the white powder alum and the bulb of a second thermometer with powdered iodine. Exposing both bulbs at the same distance to the radiations from an ordinary gas jet, he found the alum-coated thermometer rose nearly twice as high as the other; alum was a better absorber than iodine. "The radiation," he remarked, "from the clothes which cover the human body is not at all, to the extent sometimes supposed, dependent on their color. The color of animals' fur is equally incompetent to influence radiation."

Some of the first results of the invention of Langley's bolometer were to show that the maximum heat of the solar spectrum is in the orange, not in the infra-red, as Herschel had supposed. It proved, moreover, that the white light from the sun is not the sum total of the solar radiations—that the sun's true color is blue and only the orange veil of the terrestrial atmosphere works through its selective absorption on sunlight, letting through the red rays and absorbing the blue, to produce the effect of white. Strictly speaking, we should say with Professor Langley that the atmosphere absorbs all the colors, but selectively taking out more orange than red, more green than orange, more blue than green. "As there are really an infinite number of shades of color in the spectrum," says Langley, ". . . it is merely for brevity that we now unite the more refrangible colors under the general word 'blue,' and the others under the corresponding terms 'orange' or 'red.' ".

Newton showed that white light is compounded of blue, red, and other colors; by turning a colored wheel rapidly all blend into a grayish white. Arrange them so that there is too much blue, and the combined result is a very bluish white, that of the original sun ray. Alter the proportion of colors so as to virtually take out the excess of blue, and the result is colorless or white light. White, then, is not necessarily made by combining the "seven colors," or any number of them, unless they are there in

just proportion (which is in effect what Newton himself says); and white, then, may be made out of such a bluish light as we have described, not by putting anything to it, but by taking away the excess which is there already.

Langley and T. W. Very showed by studying the radiations of the firefly "that it is possible to produce light without heat, other than that in the light itself; that this is actually effected now by nature's processes; that nature produces this cheapest light at about one four-hundredth part of the cost of the energy which is expended in the candle flame, and at but an insignificant fraction of the cost of the electric light."

Langley showed also that the amount of energy necessary to produce the sense of color varies enormously with the color. The sensation of red, for example, requires that the energy of the waves which enter the eye shall be 100,000 times as great as the energy necessary to produce the impression of green. Far down below the visible red of the solar spectrum the delicate filament of Langley's bolometer groped its way until a point was reached at which the solar radiations seem to be suddenly cut off. From terrestrial sources, however, he obtained still further wave lengths which exceeded in length .03 of a millimeter (or more than .001 of an inch).

Rubens and Nichols, using a modified form of Crookes' radiometer, found still longer wave lengths, equal to about 1-100 the length of the shortest Hertzian waves. Thus radiations of almost every length, from the great electric oscillations of Hertz several miles long down to the ultraviolet rays less than .000009 of an inch, have been definitely measured. Enormous strides have been made in the measurement of all kinds of radiations, thanks to the invention of the Hertz receiver—the "electric eye," as Sir W. Thompson calls it—a simple instrument, "nothing but a bit of wire or a pair of bits of wire adjusted so that when immersed in strong electric radiations they give minute sparks across a microscopic air gap." Thus Sir

Oliver Lodge. It was the theory of that great mathematician James Clerk-Maxwell, that light and electricity are fundamentally one, upon which Hertz conducted his studies leading to the production of those wonderful waves which to-day, through the improvements of Marconi, convey messages a thousand miles through empty air. In a lecture delivered a few years before the close of the nineteenth century Lodge said of such oscillations:

"Light is an electro-magnetic disturbance of the ether. Optics is a branch of electricity. Outstanding problems in optics are being rapidly solved now that we have the means of definitely exciting light with a full perception of what we are doing and of the precise mode of its vibration.

"It remains to find out how to shorten down the waves —to hurry up the vibration until the light becomes visible. Nothing is wanted but quicker modes of vibrations. Smaller oscillators must be used—very much smaller—oscillators not much bigger than molecules. In all probability—one may almost say certainly—ordinary light is the result of electric oscillation in the molecules of hot bodies, or sometimes of bodies not hot—as in the phenomenon of phosphorescence.

"Any one looking at a common glowworm must be struck with the fact that not by ordinary combustion, nor yet on the steam engine and dynamo principle is that easy light produced.

"So soon as we clearly recognise," he concludes, "that light is an electric vibration, so soon shall we begin to beat about for some mode of exciting and maintaining an electrical vibration of any required degree of rapidity. When this has been accomplished the problem of lighting will have been solved."

CHAPTER VIII

SOUND

THERE is no more general instinct in man than the love of the music of Nature. Often, too, the light accents of almost inaudible sounds are more eloquent and persuasive than the louder vibrations heard in a world where every smallest particle of matter vibrates. The whole physical universe is but a fathomless ocean of vibrations, altho only a few of these appear as audible sound. Yet in human history no physical sense has had such fateful influence as that of hearing. The vocal Memnon of Egypt, the oracles of Greece, the war-trumpets of Rome, the vibrant harp-strings of the Scandinavian skald, the shrill call of the bagpipes, the booming tree-drums of the South American Indians, the violin of Rouget de Lisle, the triumphant crash of the modern regimental band or massed symphony orchestra, finally the human voice in all time—it needs but a glance at a few such examples to prove how surpassing is the influence of the sounds that impinge upon the ear on the mind.

It is said that Apollo was once wandering along the shore of the Mediterranean Sea and found there the shell of a dead turtle with a few strings of dried flesh stretched across it. He held it up and delighted himself with the musical sound which it made in the wind. He plucked the strings and found they made a pleasing sound together. Such was the origin of the lyre. Pythagoras constructed on this model an instrument of a single string—the mono-

chord—which was capable of producing notes of various pitch. The string was stretched above a board, and running over a bridge was attached to weights by means of which the tension on the string could be adjusted.

Strange theories the Greeks had as to the nature of sound. Not the least curious of these theories was that enunciated by Alcmaeon of Crotona, who wrote: "We hear with the ear because it contains a vacuum"! Little as they knew of what is called to-day the science of sound, however, the Greeks carried the theory of music to a high degree of development. They were familiar with the diatonic scale of C and wrote massive bass melodies, using the natural notes, these melodies being classified as "modes," according to the note upon which the melody ended. They had six such modes ending on every note of the scale except the seventh. The accompaniment was put in above the melody in a manner exactly the reverse of that now generally in use. The so-called Ionian Mode corresponded to the modern scale of C natural, the Mixolydian to that of G natural, the Æolian to the scale of A minor. These same modes, adopted from the Greek by St. Ambrose and added to by St. Gregory, became the basis of many of the grand melodies still extant in the ritual of the Catholic Church. The Greeks also recognised three genera or varieties of modulation—the Diatonic, the Chromatic and the Enharmonic. The latter contained intervals smaller than a semi-tone—the least difference of pitch to which modern ears are accustomed. The peripatetic school of philosophers held that the higher the pitch of a sound the greater was its velocity; they also believed that the source of a sound determined the speed of its transmission, errors which were not disproved until early in the seventeenth century.

Oracles played an important part in the history of Grecian development, as in fact in that of most ancient nations. The simple device of a speaking tube made it possible to produce those mysterious voices whose super-

natural revelations so swayed the imagination of an unsophisticated people. Such were the cryptic and potent utterances of the famous Greek oracle at Delphi. To the modern mind, accustomed to wonder at nothing, to explain everything, the faith of men in the oracular utterances of antiquity seems as barbarous, childish; yet the roar of trains and machinery, the whistles, bells and rattling wheels of commerce cannot drown the quiet voice of the savant, the man who knows. The oracle still speaks, but speaks to-day from the mysterious retirement of the laboratory with an authority as absolute as that which bid the Athenians defend their city with wooden walls.

It is apparent that the multitude of sounds which reach the ear must be conveyed to it by some material medium. In most cases this medium is the air; indeed, the striking fact has long since been pointed out that but for this atmospheric ocean the world would be plunged for us in perpetual silence. The bell-jar experiment of Francis Hauksbee, made in the seventeenth century, proved that no sound is audible in a vacuum. The ringing of a bell became rapidly fainter when the air was exhausted from the bell-jar under which it was placed.

The fact that air is not the only conductor of sound nor the best is well known. Tapping a table, the sound is heard much more distinctly when the ear is placed close to the wood; the Indian places his ear near the ground to note the sound of approaching footsteps; an oncoming train is heard through the rails long before the sound of it reaches through the air; the detonation of a distant explosion comes with a double shock, the sound traveling faster through the earth than through the air. In general, then, the more dense the medium is, the better conductor does it become of sound waves. Liquids transmit the vibrations of sound better than gases. Stones clapped together under water produce a sharp stunning effect upon the ear placed under water to hear them. The bell signals

installed on the American coast give practical evidence of the superior transmitting power of water over air.

The velocity of sound in air was investigated in the sixteenth century by Marin Mersenne. Noting the difference in time between the flash and the report of fire-arms at known distances, he got 1,380 feet per second as the speed of propagation of sound waves. This result was far from accurate. Pierre Gassendi, making similar experiments, used guns large and small and disproved the Aristotelian theory that the velocity of sound was dependent upon source and pitch. To any one indeed in modern days this idea of the peripatetic school must appear absurd, for the pitch and the source of sounds from a modern orchestra are as various as musical genius can make them, yet when played together the sounds of all reach the ear at the same moment.

That the source of sound does not affect the speed of its transmission is not, however, universally true. Captain Parry, on his Arctic expedition, found that violently loud sounds would travel faster than softer ones. During artillery practice it was shown that by persons at distance from the guns the report of the latter was heard before the command of the officer to fire. In a series of experiments upon the velocity of sound in rocks Mallet showed that with a charge of 2,000 pounds of gunpowder the average velocity of the sound of a blast was 967 feet per second, while a charge of 12,000 pounds produced a speed of transmission of 1,210 per second. Through iron the speed of sound has been shown to be still faster. M. Biot, experimenting with an iron tube 3,120 feet long, found the speed of sound through this tube to be 9 or 10 times as fast as in air. It is now generally conceded that the speed of sound in iron is actually about five times as fast as in air and through water about four times as fast.

The great law of Inverse Squares which has been shown to be so general in physics applies also to Sound. If four bells of the same kind are placed at a distance of 20 yards

from the ear and another at a distance of 10 yards the single bell produces a sound as loud as that of the four. How far a sound is audible depends upon its loudness. The report of a volcano at St. Vincent was heard at Demerara, 300 miles away, and the cannons of the battle of Waterloo are said to have been audible at Dover.

The study of sound in music, the classification of tones and their combination reached a high point of development long before any complete analysis had been made of the cause of sound and the manner of its transmission. About the end of the seventeenth century Joseph Sauveur, a poor adventurer who found his way on foot to Paris seeking his fortune, became professor of mathematics at the Collège Royal. He published important papers on the discovery of "overtones" in strings, using paper riders to locate the points of greatest and least motion when the strings were set in vibration. He had observed and explained the phenomenon of sympathetic vibration. From the "beats" produced by organ pipes of nearly equal length he determined the vibration rates of the notes given forth by each. Two pipes were tuned in the ratio of $24 \div 25$. When air was blown into these four beats per second were observed, from which Sauveur concluded that the higher pitched pipe was producing 100 vibrations per second.

The experiments of William Noble and Thomas Pigott at Oxford had proved that the vibration of a string is greatest at the center and that it may also be made to vibrate in halves, thirds, fourths, fifths, etc. The strings of a harp or piano, for example, vibrate chiefly as a whole —that is, throughout their entire length. The harder the string is plucked or struck, the louder is the sound and the more ample is the motion of the string. Thus amplitude of vibration was seen to be a determining factor in the loudness of a sound.

Not only nearness and amplitude of vibration, but echo as well may increase the intensity of a sound. Speaking tubes, megaphones and such devices depending upon this

principle were in use long before the theory of sound was generally understood. The effect here is evidently one of reinforcement by echo, which in smooth tubes is so great that M. Biot observed that a conversation could be carried on in a low tone through a small tube 1,040 yards long. For very long distances, however, it is evident that the speaking tube is not a practicable device, as it would require 8 minutes for the sound to travel from one town to another 100 miles away—less than $^1/_{10}$ of the distance easily and instantly bridged to-day by the wireless telegraph.

The "father of acoustics" introduced about the end of the eighteenth century a new chapter in the study of sound. Ernst Florens Friedrich Chladni, educated for the law, proved himself a much better scientist than lawyer. He experimented with vibrating plates covered with sand. The collection of the sand at the nodes, or points of least vibration, formed the famous "figures of Chladni." These were exhibited before Napoleon, and the conqueror of Europe presented him with 6,000 francs to enable him to translate into French his Akustik. Chladni invented a torsional pendulum in which the motive force of gravity was replaced by the molecular resistance of a rod to the effect of twisting; he made many calculations of the absolute rate of vibration of sounding bodies and determined the velocity of sound in other gases than air by filling organ pipes with the gas and noting the resulting pitch.

Felix Savart, the greatest master of his time in the theory of sound, invented a simple but effective instrument to show that the vibration rate of a body is the sole factor in the pitch of the note which it produces. A toothed wheel was made to rotate rapidly against the edge of a card. By increasing or decreasing the speed of rotation the pitch of the note produced could be raised or lowered at will. A dial indicated the number of shocks per second made by the teeth of the wheel striking the card.

Caignard Latour invented about the same time an in-

strument often heard to-day in connection with steam whistles—the siren—so called because it could produce sounds audible in water as well as in air. A current of air blown through holes in a swiftly revolving disk produced notes which could be regulated to give any desired pitch. This apparatus of Latour was used by Savart with certain improvements to determine the limits of audible

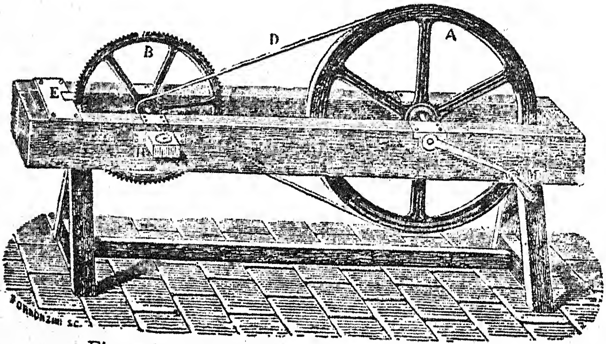


Fig. 16 —Sound Vibration Measurement.

sounds. He found that he could hear tones of bodies vibrating at the rate of 48,000 per second. The lower limit of audible vibration he placed at 16 or 14 per second. With the same velocity the siren gives the same sound in water as in air and all gases. Thus the number of vibrations per second, irrespective of the material of the vibrating body, was proved to be the sole factor in determining pitch. It is interesting to note that the siren has been applied to find the rapidity of motion in the buzzing wings of insects. The tiny gauze pinions of the gnat have thus been found to vibrate 15,000 times in a second.

About the middle of the last century was invented an instrument so similar to the human ear that it deserves some attention. E. Léon Scott produced an apparatus

which he called the Phonautograph, so beautifully constructed as to register not only the vibrations produced by solid bodies, but also those produced by wind-instruments, by the voice in singing, and even such noises as that of thunder or the report of a gun. A small cask of plaster of Paris, perhaps a foot and a half long, was closed at one

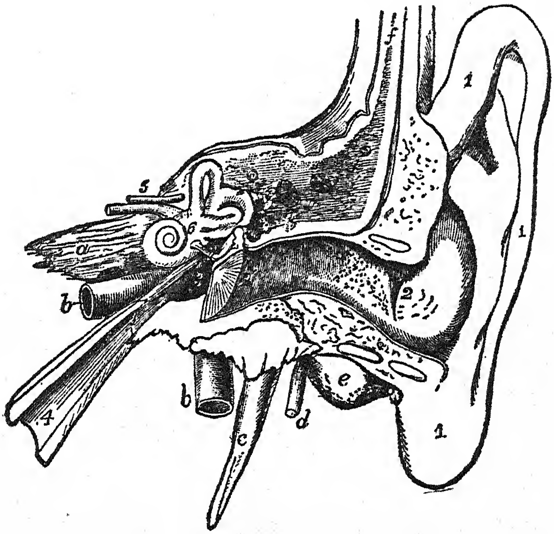


Fig. 17 —Mechanism of the Ear.

end but for a small circular space over which was fitted a flexible membrane. Plaster of Paris was selected on account of its absence of elasticity and its very slight susceptibility to vibration. A stylus or blunt needle in contact with the membrane recorded the vibrations of the latter upon a revolving cylinder. A movable piece, called the subdivider, enables the experimenter to adjust at will the arrangement of the lines of greatest and least vibra-

tion. Comparing the ellipsoid cask with the auditory canal, the stretched membrane with the tympanum or drum of the ear and the subdivider with the chain of little bones which touch the tympanum, the likeness of this instrument to the organ of hearing becomes singularly apparent.

Before the researches of Savart it was generally as-

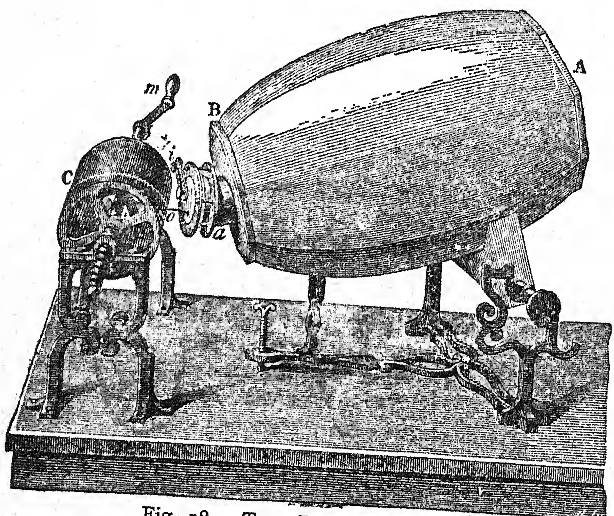


Fig. 18 —The Phonautograph.

sumed that sounds above 18,000 per second and below 32 per second were inaudible to human ears. M. Despretz, investigating the same subject, disputed Savart's results, maintaining that the higher and lower limits of audible sounds were respectively 73,700 vibrations and 32 vibrations per second. It is probable that the ears even of trained experts will vary greatly in their sensibility to sounds of extreme pitch. The intensity of a sound will

also evidently make it audible when another less intense sound of the same pitch cannot be heard at all.

The question of the quality of sounds was first clearly explained by the great Helmholtz. His 'Lehre von den Tonempfindungen' has gone through many German and English editions. This wonderful investigator, mathematician and physicist showed that musical tones were due to regularity of vibration, discordant tones to irregularity. Musical tones he distinguished by their Intensity, Pitch and Quality. The Quality of a sound he found depended upon the number of "upper partials," or "overtones," present in the vibration of any body. The electrician Georg S. Ohm was the first to point out that there is only one form of vibration which will give rise to no "overtones," but consists only of the fundamental note. This was the vibration peculiar to the pendulum and tuning fork. Helmholtz's experiments showed analytically the composition of vowel qualities, how the infinite subtleties of inflection in the human voice are due not so much to the loudness or softness of the instrument as to the number and position of these upper tones present with and sounding with the fundamental. "If only the unevenly numbered partials," says he, "are present (as in narrow stopped organ pipes, piano strings struck in their middle points, and clarinets), the quality of tone is hollow, and, when a large number of such upper partials are present, nasal. When the prime tone predominates the quality of tone is rich, but when the prime tone is not sufficiently superior in strength to the upper partials the quality of tone is poor." Helmholtz designed a series of glass globes, "resonators," which he had made of such size as to correspond with the vibration numbers of the upper partials of a given fundamental tone. When the fundamental tone was sounded, he held each one of these resonators to his ear, and if that particular overtone were present it would at once be reinforced and exposed by the resonator. Thus he proved beyond question the fact that it is the overtones of any

given note which lend to it its peculiar character, tone-color or timbre.

Rudolf König, the eminent instrument maker of Paris, constructed a series of resonators which were an improvement upon the design of Helmholtz. He made his

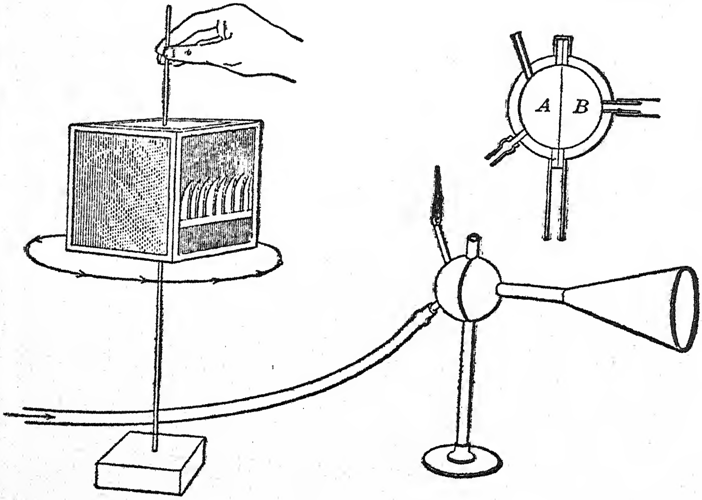


Fig. 19 —Manometric Mirror.

resonators cylindrical in form, having over one end a close-fitting cap, by means of which the cylinder could be drawn out and tuned to a nicety. Then he conceived the brilliant idea of arranging these resonators on a frame connected with a manometric mirror, whereby the presence of each and every overtone could be instantly detected by the dentations of the flame.

But Helmholtz was not content with the analysis of tones according to their quality. He verified his results by the synthesis of the same tones from their constituents.

By means of a series of electro-magnets he succeeded in making all possible combinations of overtones and producing notes of every quality.

Professor Ganot's Eléments de Physique thus summarizes the facts which the inestimably valuable researches of Helmholtz have contributed to the study of tone-color:

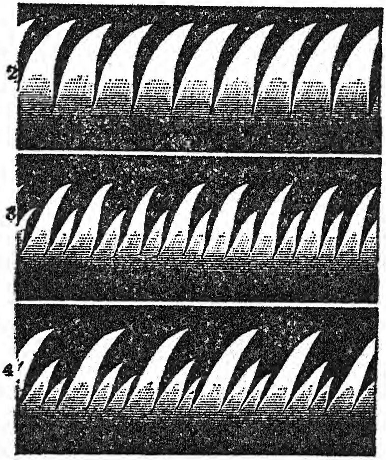


Fig. 20 —MANOMETRIC FLAMES.
Different tones produce variant flame effects.

1. Simple tones, as those produced by a tuning-fork with a resonance box, and by wide covered pipes, are soft and agreeable without any roughness, but weak, and in the deeper notes dull.

2. Musical sounds accompanied by a series of harmonics, say up to the sixth, in moderate strength are full and musical. In comparison with simple tones they are grander, richer and more sonorous. Such are the sounds of open organ pipes, of the pianoforte, etc.

3. If only the uneven harmonics are present, as in the case of narrow covered pipes, of pianoforte strings struck in the middle, clarinets, etc., the sound becomes indistinct; and when a greater number of harmonics are audible the sound acquires a nasal character.

4. If the harmonics beyond the sixth and seventh are very distinct the sound becomes sharp and rough. If less strong, the harmonics are not prejudicial to the musical usefulness of the notes. On the contrary, they are useful as imparting character and expression to the music. Of this kind are most stringed instruments and most pipes furnished with tongues, etc. Sounds in which the harmonics are particularly strong acquire thereby a peculiarly penetrating character, such as those yielded by brass instruments.

M. Jul. Ant. Lissajous designed a method of tracing by means of a stylus the vibrations of two tuning forks, known as 'Lissajous' figures.' Nathaniel Bowditch, of Salem, Mass., had also previously to Lissajous' experiments succeeded in producing the same figures.

From the evidence of the researches of Helmholtz it is evident that a pure tone is almost never heard. The notes of a violin, or of a beautiful voice, or of a piano sound, it is true, like simple tones. They are not simple—in fact, the most pleasing tones which can be heard are as a rule very complex. A note struck on the piano sounds forth simultaneously a number of other notes. These may not at first appear, but if the note struck is held down for a few minutes even the untrained ear will infallibly distinguish other notes of higher pitch which seem to take shape and stand forth separately from the sounding interior of the instrument. These auxiliary tones are frequently classed under the general head of "haromnics." Helmholtz called them "upper partials." Tyndall gave them the name of "overtones." The strings of a violin or 'cello may likewise be made to produce different notes by setting them into vibration with the bow in the usual way and merely

touching the vibrating string at various points. Violin soloists become phenomenally skilled in the use of these harmonics, which can be produced with equal readiness on the stopped or on the open strings. The same effects may be observed in a piano if the string happens to be accessible. From any string under tension harmonic effects may be obtained. Let the A string of a 'cello, for example, be bowed and at the same time lightly touched in the middle by a finger. A note will at once appear which is the octave above the open string, and the string will be seen to be vibrating in two sections in place of one. A paper rider will remain quiet when placed in the middle of the string, but if the latter is made to vibrate throughout its whole length the rider will be violently thrown off. Again, the string may be divided by a touch and made to vibrate in thirds or fourths or fifths. Dividing the string in thirds is clearly equivalent to multiplying its vibration number by 3. Each of these divisions will therefore give out a note whose vibrations are three times as frequent as those of the fundamental; in musical terms this note is said to be an octave and a fifth above the open string. If the vibration number of the A string be taken at 213 vibrations per second, the octave and fifth (E′) will then vibrate three times as frequently, giving 639 vibrations per second. (These figures, while not quite accurate, are close enough to illustrate by a rough computation how the values of harmonics were determined.) Dividing the same string of 213 vibrations per second into four parts, a note is obtained two octaves above the open string (A′), and the vibration number of this note will, in the same manner, be four times that of the fundamental, giving therefore the number 852. The division of the string into fifths produces a note which has five times the vibration frequency of the fundamental. This note will prove to be C″#—two octaves and a third above the original note. A little careful experimentation will show that several still higher harmonics may readily be produced by this one string.

The harmonics produced by sounding a note on the piano and listening for its overtones will usually appear the wrong order, the higher harmonics, on account of their more dissonant relation with the fundamental coming to the fore first.

The natural series of overtones follows in whole tones after the seventh. But none of these are exactly in tune, and after the G″ A″ B″ C‴# have been passed a partial tone appears which cannot be located by the notation in common use to-day.

In the pitch generally recognised by physicists C′ has a vibration frequency of 256 per second. "International Standard Pitch," so called, is made slightly higher than this in the endeavor to lend a more brilliant quality to the instruments. The pitch of a given note, therefore, is not always constant. A brief consideration, however, will show that not only is this the case, but that the tone-relations of a note are not constant and that the same note in different natural scales must have a different vibration-rate. The fact is that the natural scale in use to-day is not natural but artificial; the diatonic scale is not diatonic. For purposes of modulation it became necessary to "temper" the natural series of notes which would occur as overtones from a given fundamental. Thus the "perfect fifth" (G) above the note C is actually about $^1/_{50}$ of a semi-tone flat, and the F next below it is made sharp to a still greater extent, while the other notes of the scale are tempered more than these. A perfectly "tuned" piano has not a single note (excepting the octaves) in tune. The complex nature of the apparently simple major scale may easily be made apparent.

The scale from C to C′ has in it eight natural notes (white) and five "accidentals" (black). Excluding the octave, this makes then twelve notes. Theoretically the major scale was originally derived from the first few overtones of a given fundamental. All the natural notes of the scale, except the seventh, are found in the overtones of the

note C. But the interval from the first to the second note of the scale is not the same as the interval from the second to the third. The introduction of minor melodies and a minor scale made the problem still more difficult, for the ratio between E♭ in the "perfect" scale and C is not at all the ratio between D# in the "perfect" scale and the same note C. Consequently D# and E♭ must both be altered to some intermediate note, since in an instrument (like the piano) of fixed pitch the same key must be struck to represent both these notes. The problem was finally solved by dividing the notes from C to its octave above (C′) into twelve equal steps or intervals, and by this means producing a "tempered" scale of which the notes, black or white, could be played in any key. For this instrument

	NATURAL	TEMPERED
c	24	24
c# d♭	..	25.43
d	27	26.94
d# e♭	..	28.55
e	30	30.25
f	32	32.05
f# g♭	..	33.96
g	36	35.98
g# a♭	..	38.12
a	40	40.38
a# b♭	..	42.80
b	45	45.33
c‿	48	48

so tuned Johann Sebastian Bach, the greatest of all great composers, wrote his Das Wohltemperirte Klavier, showing that with these fixed and tempered notes music could be played in any key whatsoever. It is related of the great Handel that he could not bear to hear music played in the tempered scale, and had constructed for himself an organ provided with keys to produce every one of the

notes theoretically necessary for a perfect scale. This would really require a keyboard containing about twenty notes to the octave, and more than this if such accidentals as double sharps and flats be accurately represented! A glance at the accompanying table will show how each note of the tempered scale compares with its true value in the natural scale.

It is a problem for the "musical" physicist of the future to devise a keyboard adapted to play in perfect tune the perfect scale in every key.

Musical instruments are among the earliest recorded human inventions. In the Hebrew scriptures mention is made of one Jubal, who became "the father of all such as handle the harp and the organ." The Hebrews had many musical instruments—harps, trumpets and flutes of various styles. The Egyptian inscriptions likewise portray types of all these instruments. They developed also an organ, a set of pan-pipes with bellows. From the Phenicians the Greeks are said to have imitated the cithara, zither or lyre. The Sabeca of the Chaldeans was the precursor of the modern harp, the Psautêrîn of the clavichord, from which evolved the modern piano. The bagpipes were known from the very beginning of history in Syria, Phenicia and Egypt. Such early instruments as these were designed rather to accompany singing and religious ritual than for solo performances. The use of instruments unaccompanied by the human voice is an essentially modern idea.

The infinite combinations of tone heard in a modern orchestra are the product of four main classes of instruments:

(1) The Strings.
(2) The Wood Wind Instruments.
(3) The Brass Instruments.
(4) The Percussion Instruments.

More than half of a well-balanced orchestra to-day is made up of stringed instruments—the Violins, Violas, 'Cellos and Bass Viols. As the latter three are identical

in general construction with the violin, the difference being mainly one of size, a word concerning the latter will of course apply to all in this group.

The vibration of the strings alone of a violin, made by drawing a bow across them, would have so little resonant value that the sound would be almost inaudible and the instrument about as serviceable in an orchestra as a jew's-harp. The tone must therefore be reinforced, and this is

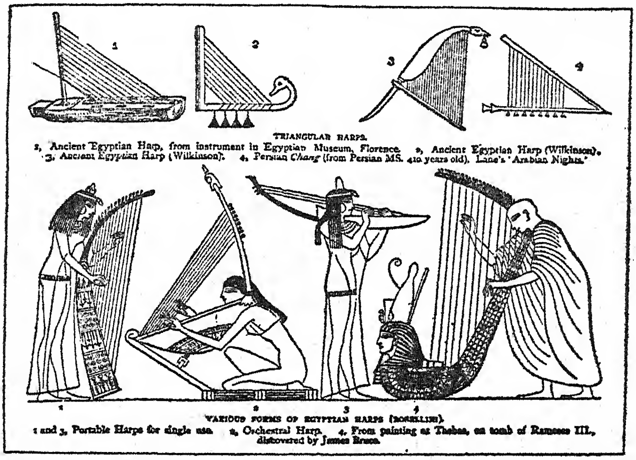


Fig. 21 —EARLY STRINGED INSTRUMENTS.

done by the body of the violin, every part of which is forced into vibration when the strings vibrate. A just proportion in the construction of the violin "box" is the secret which the great Cremona violin makers—the Guarnerii and Stradivarii—discovered. The wood must not be too thick, for the vibration then will be dull and smothered, nor too thin, for then the tone of the instrument lacks body, richness, mellowness. The material must be perfectly seasoned, so that no subsequent contraction of the

fiber may strain and destroy the perfect proportion of the parts of the instrument. The adjustment of the bass-bar beneath the heaviest string and supporting one foot of the bridge; of the sound post which supports the other foot of the bridge; the adjustment, carving out and proportioning of the bridge itself; the length of neck and size of head; the varnish which fills and protects the surface of the wood; the shape of the body; the position, size and shape of the sound-holes—all these and other conditions affect the construction of a perfect instrument. By bowing nearer to or farther from the bridge the tone is made either bright or soft and mellow. If the vibration is excited near the bridge, a large number of the higher overtones are brought out; if farther away the fundamental and primary overtones assume greater prominence, for the larger the segments in which the principal vibrations occur the less will the tone be affected by the higher partials. If the string is bowed too far from the bridge it loses its sonorous quality and becomes feeble in tone. The violin string, therefore, is bowed at points which vary from $1/8$ to $1/12$ of the string-length from the bridge, and the instrument is thus able to produce more varieties of tone-color than are found in any other one instrument.

In the others of this class the quality of tone grows gradually more somber as the instruments increase in size and weight, and the greater size of string necessitates bowing farther from the bridge. Even the bass viol (or violone), however, may be used occasionally as a solo instrument, giving a magnificently rich, ponderous tone.

The production of sound in the brass instruments depends upon the use of overtones. The fundamental ("pedal") notes of these instruments are seldom heard. In the bugle, the simplest of the brasses, the second, third, fourth and fifth overtones are alone used. For example, a C bugle will produce among its natural overtones the notes G, C′, E′, G′, and with these four notes, by aid of change of rhythm, all the military signals may be pro-

duced. A trombone, if in this key, would add to these notes the octave C. Here, however, a new principle is introduced—by means of the slide the length of the trombone tube may be increased. Suppose the slide to be pushed out about an inch and a half, it is clear that the pitch of the whole instrument will be lowered; it will give exactly the same series of overtones, but each will be found about a semi-tone below its original pitch, thus producing the notes F#, B, D#, F#. (It should be noted that a trombone is exactly an octave lower than a bugle, cornet or trumpet in the same key.) Pushing the slide out another inch and a half again lengthens the tube and again lowers the instrument a semi-tone, giving the series F, B♭, D, F. This is actually the key in which the orchestral trombone lies with slide closed. By repeating this process of lowering the slide all the semi-tones in the scale may be produced as far as the compass of the instrument extends. The pedal note of the trombone may similarly be lowered by means of the slide.

In all the brass instruments other than the slide trombone the overtones are lowered by means of finger valves which introduce different lengths of pipe into the vibrating tube. The trombone is not infrequently (especially in brass bands) provided with such valves in lieu of the slide, and the physical principle of the instrument then becomes identical with that of the French horn, cornet, trumpet and tuba.

The French horn produces a tone singularly soft among the brasses, sounding often more like some wood wind instrument. The quality of tone of this instrument has been explained on the basis of the conical bore of the tube and the immense bell at the end of it. The sound is softened and mellowed by the oblique reinforcement of echo from the walls of the tube. The trumpet, on the contrary, by far the most brilliant instrument in existence, is said to owe its superiority in this regard to the cylindrical bore

and small bell of the tube. The vibrations are not lost as in the spreading walls of the French horn, cornet, etc.

The wood wind instruments are of three types. The flute and piccolo (or octave flute) are made to sound by the breath of the player blown across a hole in the instrument and striking the opposite edge. Different notes are produced by the keys, which open holes in the side of the flute, thus causing the air within to vibrate in various sections at the will of the player.

The oboe, English horn (or tenoroon) and bassoon have two thin reeds in the mouth-piece which set into vibration the column of air within the instrument. The extremely reedy tone of this instrument has caused it to be used a great deal for pastoral effects in what is called "descriptive" music. This penetrating, soft, but reedy quality, when brought down into the bass register as in the bassoon, has an effect sometimes ludicrous, sometimes terrifying, always peculiarly characteristic. The "flutes" of the Egyptians are believed by some authorities to have been in reality of the oboe type. It is probable that they frequently used reeds in the end of the pipes and that the latter would be classed to-day as either oboes or clarinets.

The clarinet principle is not essentially different from that of the oboe, except that it has one reed instead of two. The instrument is made in several pitches. A high clarinet in E*b* is much favored in band music, but appears seldom in orchestra. There are also a bass and an alto clarinet which are recognised by composers, these instruments being identical in principle with the A and B*b* clarinets of an orchestra. The quality of these instruments partakes of both the soft floating notes of the flute and the highly nasal character of the oboe.

Altho there is probably no instrument so primitive as the drum, yet the kettle drums of the modern orchestra are by no means primitive instruments. Their value is chiefly in the tremendous energy which they add to rhythmic effects, but they can also be tuned through a

surprisingly wide range of notes, altho of low pitch and dull quality of tone, producing no definite musical tone-color. The copper hemisphere above which the sheepskin head is stretched acts as a perfect resonator, and the tone of the drum, partly on account of this large reflecting surface, has an amazing carrying power.

Of other percussion instruments, such as the cymbals, snare drum, tambourine, xylophone, etc., which have come down with little or no change from the earliest times, only passing mention need be made.

A familiar but very beautiful instrument, different in principle from any of those heretofore mentioned, is the Æolian harp. In this the strings are set in motion by the varying currents of wind upon them. Since no resonator reinforces the tone of the strings, the quality of the sound is exceedingly soft and ethereal, altho distinct enough in point of pitch.

Sound, therefore, like Light and Heat, may be considered in a double aspect, that of the physicist and that of the artist or musician. The Laws of Physics cannot be considered merely as cold abstractions, for the reason that they are so intimately related to the esthetic interests of life and the advancement of human well-being. The better understanding of the Properties of Matter has led to this era of Mechanical Knowledge, the comprehension of the principles of heat has enabled man to obviate much climatic inclemency; the length of available time for labor and pleasure has been increased by artificial lighting, and speech is dependent upon the hearing of the Sound. And even yet the vast domain of these great subjects is scarcely known, but half explored, and the twentieth century waits to welcome the Newton of the future.

ELECTRICITY

PROF. WM. J. MOORE

ELECTRICITY

CHAPTER I

THE NATURE OF ELECTRICITY

So RAPIDLY have the applications of electricity to the wants of industry followed one another during the past thirty years that it may seem as tho the whole science had been practically developed in that time, and yet the real foundation work, which make the almost innumerable electrical contrivances of to-day possible, was mainly laid long before that period. It is Gilbert, Franklin, Volta, Galvani, Davy, Arago, Faraday, Maxwell and many others who have enabled the modern experts to put much of the science on a mathematical basis, and who made long strides toward that final goal which is still so far away—the answer to the question, What is Electricity?

Many are the philosophers who are still devoting their lives to it, and occasionally some fact is discovered which disarranges many existing ideas and leads to new and unexplored fields. The new theories which have been advanced, however, have striven rather to elucidate some unexplained points of the old theories than to disprove them.

Thales in 600 B.C., who discovered the attraction of amber for light bodies, said that amber had a soul. Gilbert, in 1600 A.D., is accredited with the following hypothesis: Friction, because it heats a body, causes it to emit rays of a subtle unctuous material, which is cooled again

ELECTRICITY

CHAPTER I

THE NATURE OF ELECTRICITY

So RAPIDLY have the applications of electricity to the wants of industry followed one another during the past thirty years that it may seem as tho the whole science had been practically developed in that time, and yet the real foundation work, which make the almost innumerable electrical contrivances of to-day possible, was mainly laid long before that period. It is Gilbert, Franklin, Volta, Galvani, Davy, Arago, Faraday, Maxwell and many others who have enabled the modern experts to put much of the science on a mathematical basis, and who made long strides toward that final goal which is still so far away—the answer to the question, What is Electricity?

Many are the philosophers who are still devoting their lives to it, and occasionally some fact is discovered which disarranges many existing ideas and leads to new and unexplored fields. The new theories which have been advanced, however, have striven rather to elucidate some unexplained points of the old theories than to disprove them.

Thales in 600 B.C., who discovered the attraction of amber for light bodies, said that amber had a soul. Gilbert, in 1600 A.D., is accredited with the following hypothesis: Friction, because it heats a body, causes it to emit rays of a subtle unctuous material, which is cooled again

on coming into contact with the air, loses its expansive force, and draws itself together again, bringing back such light bodies as come in the way of the electrified body. According to Hauksbee, the emanations of matter which start from an electrified body spread in the form of rays or physical lines, which possess a kind of continuity in themselves so that those parts of each ray or line which reach out furthest into space receive the impulse from those parts which are nearest to the body.

The eighteenth century brought out two theories which for a time seemed to explain most of the phenomena then observed: one was the two-fluid theory of Symmer and the other the single-fluid theory of Franklin. Both these theories assumed electricity to be a fluid.

Franklin assumes the existence of one electric substance or fluid which attracts the particles of ordinary matter, but repels itself. In the ordinary state, bodies are charged with a normal quantity of this electrical substance. If this charge be either increased or decreased, the body becomes 'electrified'; if it be increased, the body is charged with a 'plus' or positive charge; if the body has a less quantity of electricity than in its normal state, it is said to be charged with a 'minus' or negative charge.

The two-fluid theory thought out by Symmer supposes that instead of there being one fluid there are two fluids having opposite properties to each other. The molecules of either fluid repel one another, but attract those of the opposite kind of fluid. Bodies in their normal condition, or when unelectrified, contain equal quantities of both fluids held together by their mutual attraction, so neutralizing each other. By friction or by induction the two fluids may be separated; the positive fluid passes to one of the bodies and accumulates on its surface, thus leaving an excess of negative electricity on the other. These two theories were convenient to use in explaining the action of frictional and influence machines, the electrophorus, the condenser and many other forms of

electrostatic apparatus. Indeed, these theories are still applied to a certain extent as affording a convenient means of expressing these electrostatic actions. They contain a large element of truth, and the later theory of Maxwell and the electron theory are elaborations of them.

Franklin's opinion on the nature of electricity may best be stated in his own words, and the following is an extract from his paper entitled 'Opinions and Conjectures concerning the Properties and Effects of Electrical Matter arising from Experiments and Observations made at Philadelphia, 1749':

"(1) The electrical matter consists of particles extremely subtile, since it can permeate common matter, even the densest metals, with such ease and freedom as not to receive any perceptible resistance.

"(2) If any one should doubt whether the electrical matter passes through the substance of bodies, or only over and along their surfaces, a shock from an electrified large glass jar, taken through his own body, will probably convince him.

"(3) Electrical matter differs from common matter in this, that the parts of the latter mutually attract, those of the former mutually repel each other. Hence the appearing divergency in a stream of electrified effluvia.

"(4) But tho the particles of electrical matter do repel each other, they are strongly attracted by all other matter.

"(5) From these three things, the extreme subtilty of the electrical matter, the mutual repulsion of its parts, and the strong attraction between them and other matter, arise this effect, that when a quantity of electrical matter is applied to a mass of common matter, of any bigness or length, within our observation (which hath not already got its quantity), it is immediately and equally diffused through the whole.

"(6) The common matter is a kind of sponge to the

electrical fluid. And as a sponge would receive no water if the parts of water were not smaller than the pores of the sponge, and even then but slowly, if there were not a mutual attraction between those parts and the parts of the sponge; and would imbibe it still faster if the mutual attraction among the parts of the water did not impede, some force being required to separate them; and fastest, if, instead of attraction, there were a mutual repulsion among those parts which would act in conjunction with the attraction of the sponge—so is the case between electrical and common matter.

"(7) But in the common matter there is (generally) as much of the electrical as it will contain within its substance. If more is added, it lies without upon the surface, and forms what we call an electrical atmosphere, and the body is said to be electrified.

"(8) 'Tis supposed that all kinds of common matter do not attract and retain the electrical with equal strength and force, for reasons to be given hereafter. And that those called electrics per se, as glass, etc., attract and retain it strongest and contain the greatest quantity.

"(9) We know that the electrical fluid is in common matter because we can pump it out by the globe or tube. We know that common matter has near as much as it can contain because when we add a little more to any portion of it, the additional quantity does not enter but forms an electrical atmosphere. And we know that common matter has not (generally) more than it can contain, otherwise all loose portions of it would repel each other as they constantly do when they have electric atmospheres. . . .

"(15) The form of the electrical atmosphere is that of the body it surrounds."

Such are the essential parts of Franklin's primitive theory, propounded for the purpose of giving a consistent

account of the phenomena of electric attraction and repulsion so far as they were known in his time. It is curious to observe how some of his ideas were quite in keeping with the latest theory—the electron theory—described later.

Various theories were propounded from time to time for a long time after the enunciation of the single and two fluid theories, but none served better as a working basis. In the latter part of the nineteenth century, however, a new theory dealing with electricity as obeying the laws of mechanics was formulated by Clerk Maxwell, the great English physicist. Maxwell's ideas were founded on the observations made by Faraday, who discovered that the nature of the insulating material, or dielectric, between the plates of a condenser had a great deal to do with the quantity of electricity which would flow into it under the influence of a given electromotive force. This fact led Maxwell to believe that the dielectric was the real seat of the charge, that the conductor acted merely to distribute the charge over the different portions of the dielectric in contact with it. When a flow of current takes place along a wire it is due to the differences existing in the dielectric about the wire. The following extract from 'Maxwell's Theory and Hertzian Oscillations,' by H. Poincaré, translated by Frederick K. Vreeland, may serve to give some idea of the action in and about an electric circuit.

"If we undertake to compress a spring," he says, "we encounter an opposing force which increases as the spring yields to the pressure. If, now, we can exert only a limited pressure, a moment will arrive when we can no longer overcome the reacting force; the movement will cease, and equilibrium will be established. Finally, when the pressure is removed, the spring will regain its original form, giving back all the energy that was expended in compressing it.

"Suppose, on the other hand, that we wish to move a body immersed in water. Here again we encounter a re-

electrical fluid. And as a sponge would receive no water if the parts of water were not smaller than the pores of the sponge, and even then but slowly, if there were not a mutual attraction between those parts and the parts of the sponge; and would imbibe it still faster if the mutual attraction among the parts of the water did not impede, some force being required to separate them; and fastest, if, instead of attraction, there were a mutual repulsion among those parts which would act in conjunction with the attraction of the sponge—so is the case between electrical and common matter.

"(7) But in the common matter there is (generally) as much of the electrical as it will contain within its substance. If more is added, it lies without upon the surface, and forms what we call an electrical atmosphere, and the body is said to be electrified.

"(8) 'Tis supposed that all kinds of common matter do not attract and retain the electrical with equal strength and force, for reasons to be given hereafter. And that those called electrics per se, as glass, etc., attract and retain it strongest and contain the greatest quantity.

"(9) We know that the electrical fluid is in common matter because we can pump it out by the globe or tube. We know that common matter has near as much as it can contain because when we add a little more to any portion of it, the additional quantity does not enter but forms an electrical atmosphere. And we know that common matter has not (generally) more than it can contain, otherwise all loose portions of it would repel each other as they constantly do when they have electric atmospheres. . . .

"(15) The form of the electrical atmosphere is that of the body it surrounds."

Such are the essential parts of Franklin's primitive theory, propounded for the purpose of giving a consistent

account of the phenomena of electric attraction and repulsion so far as they were known in his time. It is curious to observe how some of his ideas were quite in keeping with the latest theory—the electron theory—described later.

Various theories were propounded from time to time for a long time after the enunciation of the single and two fluid theories, but none served better as a working basis. In the latter part of the nineteenth century, however, a new theory dealing with electricity as obeying the laws of mechanics was formulated by Clerk Maxwell, the great English physicist. Maxwell's ideas were founded on the observations made by Faraday, who discovered that the nature of the insulating material, or dielectric, between the plates of a condenser had a great deal to do with the quantity of electricity which would flow into it under the influence of a given electromotive force. This fact led Maxwell to believe that the dielectric was the real seat of the charge, that the conductor acted merely to distribute the charge over the different portions of the dielectric in contact with it. When a flow of current takes place along a wire it is due to the differences existing in the dielectric about the wire. The following extract from 'Maxwell's Theory and Hertzian Oscillations,' by H. Poincaré, translated by Frederick K. Vreeland, may serve to give some idea of the action in and about an electric circuit.

"If we undertake to compress a spring," he says, "we encounter an opposing force which increases as the spring yields to the pressure. If, now, we can exert only a limited pressure, a moment will arrive when we can no longer overcome the reacting force; the movement will cease, and equilibrium will be established. Finally, when the pressure is removed, the spring will regain its original form, giving back all the energy that was expended in compressing it.

"Suppose, on the other hand, that we wish to move a body immersed in water. Here again we encounter a re-

electrical fluid. And as a sponge would receive no water if the parts of water were not smaller than the pores of the sponge, and even then but slowly, if there were not a mutual attraction between those parts and the parts of the sponge; and would imbibe it still faster if the mutual attraction among the parts of the water did not impede, some force being required to separate them; and fastest, if, instead of attraction, there were a mutual repulsion among those parts which would act in conjunction with the attraction of the sponge—so is the case between electrical and common matter.

"(7) But in the common matter there is (generally) as much of the electrical as it will contain within its substance. If more is added, it lies without upon the surface, and forms what we call an electrical atmosphere, and the body is said to be electrified.

"(8) 'Tis supposed that all kinds of common matter do not attract and retain the electrical with equal strength and force, for reasons to be given hereafter. And that those called electrics per se, as glass, etc., attract and retain it strongest and contain the greatest quantity.

"(9) We know that the electrical fluid is in common matter because we can pump it out by the globe or tube. We know that common matter has near as much as it can contain because when we add a little more to any portion of it, the additional quantity does not enter but forms an electrical atmosphere. And we know that common matter has not (generally) more than it can contain, otherwise all loose portions of it would repel each other as they constantly do when they have electric atmospheres. . . .

"(15) The form of the electrical atmosphere is that of the body it surrounds."

Such are the essential parts of Franklin's primitive theory, propounded for the purpose of giving a consistent

account of the phenomena of electric attraction and repulsion so far as they were known in his time. It is curious to observe how some of his ideas were quite in keeping with the latest theory—the electron theory—described later.

Various theories were propounded from time to time for a long time after the enunciation of the single and two fluid theories, but none served better as a working basis. In the latter part of the nineteenth century, however, a new theory dealing with electricity as obeying the laws of mechanics was formulated by Clerk Maxwell, the great English physicist. Maxwell's ideas were founded on the observations made by Faraday, who discovered that the nature of the insulating material, or dielectric, between the plates of a condenser had a great deal to do with the quantity of electricity which would flow into it under the influence of a given electromotive force. This fact led Maxwell to believe that the dielectric was the real seat of the charge, that the conductor acted merely to distribute the charge over the different portions of the dielectric in contact with it. When a flow of current takes place along a wire it is due to the differences existing in the dielectric about the wire. The following extract from 'Maxwell's Theory and Hertzian Oscillations,' by H. Poincaré, translated by Frederick K. Vreeland, may serve to give some idea of the action in and about an electric circuit.

"If we undertake to compress a spring," he says, "we encounter an opposing force which increases as the spring yields to the pressure. If, now, we can exert only a limited pressure, a moment will arrive when we can no longer overcome the reacting force; the movement will cease, and equilibrium will be established. Finally, when the pressure is removed, the spring will regain its original form, giving back all the energy that was expended in compressing it.

"Suppose, on the other hand, that we wish to move a body immersed in water. Here again we encounter a re-

action, which depends upon the velocity, but which, if the velocity remain constant, does not go on increasing as the body yields to the pressure. The motion will thus continue as long as the motive force acts, and equilibrium will never be established. Finally, when the force is removed, the body does not tend to return to the starting point, and the energy expended in removing it cannot be restored; it

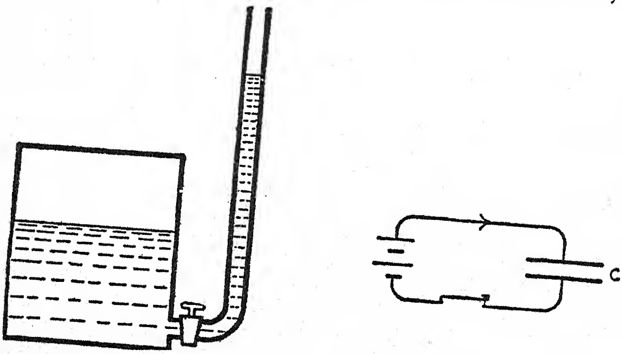


Fig. 1 —Model Illustrating Flow of a Displacement Current. The pressure in the vessel represents the voltage of the battery; the height of the column, the displacement in the dielectric; the flow of water, the charging current. The energy expended may be recovered.

has been completely transformed into heat through the viscosity of the water.

"The contrast is manifest, and it is important to distinguish between elastic reaction and viscous reaction. Now, the dielectrics behave toward the motion of electricity as elastic solids do toward the motion of matter, while the conductors behave like viscous liquids. Hence there are two kinds of currents: the displacement currents of Maxwell, which traverse the dielectrics, and the ordinary conduction currents which flow in conductors.

"The former, having to overcome a sort of elastic reaction, must be of short duration, for this reaction increases as long as the current continues to flow and equilibrium must soon be established.

"Conduction currents, on the other hand, must overcome a sort of viscous resistance, and hence may continue as long as the electromotive force which produces them.

"To take a hydraulic analogy, suppose that we have a closed vessel containing water under pressure. If we put this vessel in communication with a vertical pipe, the

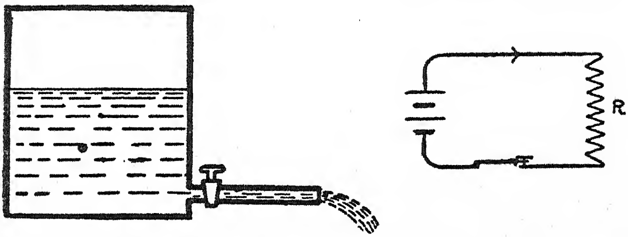


Fig. 2.—Model Illustrating the Flow of a Conduction Current.

The flow continues undiminished as long as the pressure is maintained. The energy expended in friction takes the form of heat and is lost. (From Vreeland & Poincaré, Maxwell's Theory.)

water will rise in it, but the flow will cease when the hydrostatic equilibrium is established. If the pipe be large, there will be no appreciable friction nor loss of head, and the water thus raised may be used to do work. We have here an illustration of displacement currents.

"If, on the other hand, the water be allowed to run out through a horizontal pipe (Fig. 2), the flow will continue as long as there is water in the reservoir; but if the pipe be small, there will be a considerable loss of energy, and heat will be produced by the friction. This illustrates the action of conduction currents.

"Altho it is impossible and unnecessary to try to im-

agine all the details of the mechanism, we may say that all takes place as if the displacement currents had the effect of compressing a multitude of minute springs.

"When the currents cease, electrostatic equilibrium is established; and the tension of the spring depends upon the intensity of the electrostatic field. The energy accumulated in these springs—that is, the electrostatic energy of the field—may be restored whenever they are allowed to unbend; and it is thus that mechanical work is produced

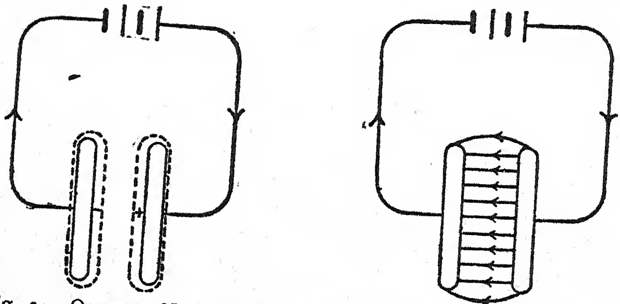


Fig. 3 —Old and New Ideas of the Charging of a Condenser. Formerly the electricity was supposed to accumulate on the surface of the plates as shown by the dotted lines. The circuit was considered unclosed. Maxwell assumes that the current does not stop at the surface of the conductor, but continues to flow through the dielectric until checked by the elastic reaction. The circuit is thus completed. (From Vreeland & Poincaré, Maxwell's Theory.)

when charged conductors are allowed to obey their electrostatic attractions. These attractions are thus due to the pressure exerted on the conductors by the compressed springs. Finally, to pursue the analogy to the end, a disruptive discharge may be attributed to the breaking of some springs which are unable to stand the strain.

"On the other hand, the energy expended in producing conduction currents is lost, and converted into heat, like the work done in overcoming friction or the viscosity of

fluids. This is why a conductor is heated by the passage of a current.

"From Maxwell's point of view, none but closed currents exist. To the early electricians this was not the case. They considered as closed the current which circulates in a wire joining the two terminals of a battery. But if, instead of joining these terminals directly, they were connected respectively to the two plates of a condenser, the momentary current which flowed while the condenser was being charged was considered as unclosed. It flowed, they said, from one plate to the other through the wire connected to the battery, and stopped at the surfaces of the plates. Maxwell, on the contrary, considers that the current continues, in the form of a displacement current, across the insulating layer which separates the plates, and is thus completely closed. The elastic reaction which the current encounters in traversing the dielectric explains its short duration.

"Currents may manifest themselves in three ways: by their heating effects, by their action on magnets and on other currents, by the induced currents which they generate. We have seen above why conduction currents produce heat and displacement currents do not. Yet, according to Maxwell's hypothesis, the currents which he imagines should, like ordinary currents, produce electromagnetic, electrodynamic, and inductive effects.

"Why could these effects not be observed? Because a displacement current, however feeble, cannot continue long in one direction; for the tension of our hypothetical springs, continually increasing, will soon check it. Thus we cannot have in a dielectric either a continuous current of long duration or a sensible alternating current of long period; but the effects should be observable if the alternations are very rapid.

"And here we have, according to Maxwell, the origin of light: A light wave is a series of alternating currents, flowing in a dielectric, in the air, or in interplanetary

space, changing their direction 1,000,000,000,000,000 times in a second. The enormous inductive effect of these rapid alternations produces other currents in the neighboring portions of the dielectric, and thus the light waves are propagated from place to place. The velocity of propagation may be known analytically to be equal to the ratio of the units—that is, to the velocity of light.

"These alternating currents are a kind of electrical vibration; but are they longitudinal, like those of sound, or transverse, like those of Fresnel's ether? In the case of sound, the air undergoes alternate condensations and rarefactions; but the ether of Fresnel acts as if it were composed of incompressible layers capable only of sliding upon each other. If the currents flowed in unclosed circuits, the electricity would necessarily accumulate at one end or the other of the circuits, and we should have a condition analogous to the condensations and rarefactions of air; the vibrations would be longitudinal. But, as Maxwell admits only closed currents, those accumulations are impossible, and the electricity must behave like the incompressible ether of Fresnel: its vibrations must be transverse.

"Thus we reach all the conclusions of the wave theory of light. This, however, was not enough to enable the physicists, who were attracted rather than convinced, to accept absolutely Maxwell's ideas: all that could be said in their favor was that they did not conflict with any known facts, and that it were indeed a pity if they were not true. The experimental confirmation was lacking, and remained so for twenty-five years.

"It was necessary to find, between the old theory and that of Maxwell, a discrepancy not too minute for our crude methods of observation. There was only one such from which an experimentum crucis could be derived. To do this was the work of Hertz."

Maxwell's electromagnetic theory, which led to the recognition of light as an electrical phenomenon and to

many other grand generalizations, was more a mathematical than a physical theory. What it chiefly accomplished was to express, in mathematical language, the experimental results of Faraday. Maxwell, however, avoided giving any description of the molecular constitution of the media through which electrical energy was transmitted.

Professor Fleming, in his pamphlet on the "Electronic Theory," says:

"It seems tolerably clear from all the facts of electrolysis that electricity can only pass through a conducting liquid or electrolyte by being carried on atoms or groups of atoms which are called ions—*i.e.,* wanderers. The quantity thus carried by a hydrogen atom or other monad element, such as sodium, silver, or potassium, is a definite natural unit of electricity. The quantity carried by any other atom or group of atoms acting as an ion is always an exact integer multiple of this natural unit. This small indivisible quantity of electricity has been called by Dr. Johnstone Stoney an electron or atom of electricity. The artificial or conventional unit of electric quantity in the centimeter-gram-second system, as defined by the British Association Committee on Electrical Units, is as follows:

"'An electrostatic unit of electric quantity is the charge which, when placed upon a very small sphere, repels another similarly charged sphere, the centers being one centimeter apart, with a mechanical force of one dyne. The dyne is a mechanical unit of force, and is that force which, acting for one second on a mass of one gram, gives it a velocity of one centimeter per second. Hence, by the law of inverse squares the force in dynes exerted by two equal charges Q at a distance D is equal to Q^2/D^2. Two other units of electric quantity are in use—the electromagnetic unit, which is thirty thousand million times as great as the electrostatic unit, and the practical unit called the coulomb or ampere-second, which is three thousand mil-

lion times the electrostatic unit. We can calculate easily the relation between the electron and the coulomb—that is, between Nature's unit of electricity and the British Association unit—as follows:

" 'If we electrolyze any electrolyte, say acidified water, which yields up hydrogen at a negative electrode, we find that to evolve one cubic centimeter of hydrogen at 0° C. and 760 mm., we have to pass through the electrolyte a quantity of electricity equal to 8.62 coulombs. For 96,540 coulombs are required to evolve one gram of hydrogen and 11,200 cubic centimeters at 0° C. and atmospheric pressure weigh one gram. The number 8.62 is the quotient of 96,540 by 11,200.

" 'From various sources calculations indicate that the number of molecules of hydrogen in a cubic centimeter is probably best represented by the number twenty million million million $= 2 \times 10^{19}$. Hence it follows, since there are two atoms of hydrogen in a molecule, that in electrostatic units the electric charge on a hydrogen atom or hydrogen ion is

$$\frac{96540 \times 3 \times 10^9}{11200 \times 4 \times 10^{19}} = \frac{65}{10^{11}} \text{ of a C. G. S. electrostatic unit} = \frac{22}{10^{20}} \text{ of a coulomb.}$$

" 'Accordingly, if the above atomic charge is called one electron, then the conventional British Association electrostatic unit of electric quantity is equal to 1,540 million electrons, and the quantity called a coulomb is nearly five million million million electrons. The electron or the electric charge by a hydrogen atom or ion is evidently a very important physical constant.'

"It is, in fact, Nature's unit, from which all other physical units may be brought into agreement with natural quantities. And thus we see that electricity is atomic in nature and in structure; that is to say, we can have it only in amounts which are all exact multiples of a certain unit, which unit cannot be subdivided, and 1,540 millions of these units equal one coulomb.

"For long it was held that the atom of matter was the

smallest particle in nature and indivisible, but now we must assume that atoms are composed by smaller particles. We are compelled by all the known facts to admit that Professor Crookes was right when he declared the cathode rays to be a stream of matter shot from the cathode. Professor J. J. Thomson, by measuring the deflection of the stream (of 'radiant matter,' as Crookes called it) in a known magnetic field, shows that, if the radiant matter consists of corpuscles or particles, each carries a charge of one 'electron,' and has a mass of about $^1/_{1000}$ of a hydrogen atom, and their velocity is from $1/5$ to $1/3$ the velocity of light.

"So far as the effects in high vacua are concerned, Professor Crookes discovered all we know about cathode rays, but Lenard conceived the idea that these rays could penetrate the walls of the vessel containing the vacuum, and by inserting a window of aluminium in the vessel he found the rays penetrated the aluminium and that they are active outside the vessel as they are inside.

"Electrons are found in the mass of gas through which Röntgen rays have passed. Röntgen discovered that if the rays from the cathode struck a conductor in the vacuum bulb, that they penetrated the glass bulb enclosing the vacuum, and that they also penetrate many opaque bodies outside, and produce photographs on active plates.

"The atom, it seems, can be divided into two parts of very unequal size. The small part is negatively electrified, and is always the same, no matter from what chemical atom it comes. The remaining larger part is positively electrified, but is different in nature, depending on the elementary atom broken up. It is not settled whether the particle and its negative charge are separable. It is, however, becoming common to speak of the two together as the 'electron.'

"From this point of view the theory of electricity originates is called the electronic theory. The principal objects of consideration in this theory are these electrons which

constitute what we call electricity. An atom of matter in its neutral condition has been assumed to consist of an outer shell or envelope of negative electrons associated with some core or matrix which has an opposite electrical quality, such that if an electron is withdrawn from the atom the latter is left positively electrified.

"A neutral atom minus an electron constitutes the natural unit of positive electricity, and the electron and the neutral atom minus an electron are sometimes called negative and positive ions. Deferring for a moment a further analysis of possible atomic structure, we may say that, with the above hypothesis in hand, we have then to express our statements of electrical facts in terms of the electron as the fundamental idea.

"On this theory the difference between conductors and non-conductors is accounted for by assuming that an electric current is a procession of electrons, so that a conductor is a substance through which electrons can easily move; in non-conductors the electrons may be moved, or vibrated, or displaced to some extent, but spring back again into their former place.

"The electronic or any theory must account for the waves set up in the ether around a variable current. This is explained on the hypothesis that a moving or vibrating electron, while its motion is being accelerated or reduced, radiates ethereal waves, and that a flying column of electrons produces a magnetic field in circles round the moving electrons as a center."

The electron theory has not yet been fully developed. Many things about it are not clear, but most scientists are agreed upon the existence of the electron and are awaiting the results of further experiments to help them decide upon its exact nature and behavior.

CHAPTER II

ELECTROSTATICS—ATMOSPHERIC ELECTRICITY

In the early days of electrical science many of the experiments in electrostatics were developed which still form a considerable part of the course usually taught in present-day schools. The attraction of amber when rubbed for light bodies was known to the ancient Greeks as long ago as 600 B.C. About the year 1600, Gilbert, who had made several discoveries concerning the properties of the magnet, discovered in glass, sulphur, resin and various precious stones the same attractive power known to be possessed by amber. From that time innumerable physicists have extended Gilbert's discoveries and have found a great number of curious phenomena previously entirely unknown, and in this way have contributed to found that branch of physics which, under the name of Electricity, has attained such important dimensions in modern times.

"If he had used a ball of glass or sulphur previously rubbed," sugests Guillemin, "he would have known of the reciprocity of attraction in the same way as he had shown that soft iron attracts a magnet. But Gilbert greatly extended the list of bodies capable, like amber, of being electrified by friction; to those that we have already mentioned he added shellac, rock salt, alum and rock crystal. He also found that electrical attraction took place not only between light bodies, but between certain solid bodies, drops of liquids, gaseous bodies, and dense vapors. Again, he discovered the influence of atmospheric conditions on electric phenomena.

"Boyle discovered the reciprocity of attraction between non-electrified bodies and electrified bodies. A very simple experiment, on the mechanical principle of action and reaction being equal and opposite, led to this discovery. On a pivot was placed a small shellac needle electrified by being rubbed by catskin. Then, on holding his finger near one end, he found the needle drawn toward his finger. Otto von Guericke, who made the first frictional electrical machine, was the first to observe the phenomena of repulsion, and he also drew from the globe of sulphur of his machine visible sparks, accompanied by a crisp crackling sound, which was in fact the noise of the electric discharge. Here we had for the first time in these early experiments the production of sparks similar to those which constitute the electric arc; tho it is a long step from these feeble sparks to the dazzling splendor of the electric light. The experiments of the celebrated burgomaster of Magdeburg date from the middle of the seventeenth century. At the commencement of the eighteenth century, that was to witness such brilliant discoveries in electricity, Dr. Wall succeeded in producing most vivid sparks and far louder crackling: he also had some ideas of the great discovery which made Franklin so celebrated. 'This light and that crackling,' said he, 'are the same thing as thunder and lightning.' The analogy was indeed striking, and it was not long before it was verified and confirmed.

"Numerous observations on the electrical phenomena were due to Hauksbee. Among them are very interesting experiments on the light which is produced in a vacuum or in a rarefied medium when one introduces some bodies into it, and develops on their surface electricity by friction; or when one excites the exterior of a globe of glass, the interior of which is a vacuum.

"He observed in particular the effect of heat on the development of both attractive and repulsive forces. The attractions and repulsions of pieces of tinsel by a tube of glass, rubbed with paper, were found to be more energetic

when the glass had been heated by friction. The effects of moisture and warmth that Gilbert had discovered were proved beyond doubt by the experiments of Hauksbee, Dufay and Gray. The following passage occurs in Hauksbee's Physico-Mechanical Experiments: 'When the tube became hottest by the strongest Attrition, the Force of the Effluvia was rendered manifest to another Sense too, namely, that of feeling. They did not then only produce all the forementioned Effects in a more remarkable manner, but were also plainly to be felt upon the Face, or any other tender part, if the rubbed Tube was held near it. And they seemed to make very nearly such sort of stroaks upon the Skin, as a number of fine limber Hairs pushing against it might be supposed to do.'

"The discovery of electrical conductivity was made in the early part of the eighteenth century by Stephen Gray. While looking for the reason of the difference between the two classes he came upon the general fact that all bodies, without exception, are capable of being electrified, but that the circumstances must be varied to suit the substances.

"Let us rapidly review the points that led Gray to this important discovery. Having electrified a piece of glass tube, the ends of which were stopped with corks, he was surprised to find that the corks, which he had not rubbed, picked up light bodies just as the tube itself did, showing that the electricity passed from the glass to the cork. Gray followed up this experiment by lengthening the corks with sticks of ivory, wood or metal, yet he had the same phenomena even with stems which ended in a ball of ivory. Hung from a balcony by a long cord fastened to the tube the ball still was electrified. He then varied his experiment to greater and greater distances, until he found the same effect at the end of a cord 765 feet long. But Gray found that in order to succeed, certain conditions had to be fulfilled; the cord which carried the electricity had to be suspended by silk strings, as he found

that he got no electrification at all if he suspended it by means of metal wires.

"One more experiment of Gray's that was soon repeated in all laboratories was to show that the human body conducts electricity. It explains the impossibility that had always been found in trying to electrify such substances as the metals. Having suspended a child by hair cords, and having touched him with his electrified tube, he found that all parts of the child's body had acquired the power

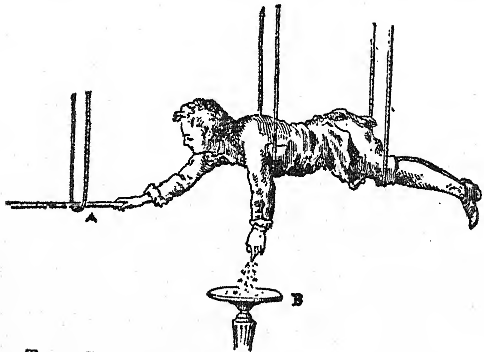


Fig. 4—The Conductivity of the Human Body: Gray's Experiment.

of attracting light bodies. The same effect was produced when the child stood on a cake of an 'electric' substance, such as resin, as was produced when he was suspended by the hair cords. From these experiments, which were then varied in innumerable ways, two very important conclusions were drawn.

"The first, that electricity obtained by friction could be transmitted to a distance through any substance that could not itself be electrified; the second, a corollary to the first, that this transmission is impossible, or very difficult, if the transmitting body is one of those capable of being electrified by the method described above.

"We quoted above Gray's first experiment, which established the electrical conductivity of the body. It was a French physician, Dufay, a member of the Academy of Sciences, who drew the first spark from the human body. 'Being suspended by silk cords, he found, when electrified, that, if any one brought his knuckle near to him, he felt a stinging sensation like a pin-prick, also that the person's knuckle felt the same sensation. When the experiment was performed in the dark a little spark was observed.'

"Gray took up the experiments of Dufay and in his turn found that he could draw sparks from any insulated body which had been put into contact with rubbed glass; if these bodies terminated in a point a small luminous cone was seen, accompanied by a slight noise. In reference to this Gray repeated Wall's comparison between the spark followed by the crackling sound and the lightning followed by thunder."

Newton's grand discovery of the law of the universal attraction of matter, when he showed that the force was proportional to the mass and that it varied in the inverse ratio of the square of the distance, incited the physicists of the eighteenth century to discover the law which governed the strength of electrical forces. Dufay, Hauksbee, Muschenbroek, Æpinus, and Cavendish were all more or less instrumental in attaining this end; but we are indebted to Coulomb for an exact experimental demonstration of these laws. Coulomb used for this purpose a similar apparatus to the magnetic balance. From the figure it will be seen that it consisted of two spheres so arranged that they could be charged and the force of repulsion between them balanced by the torsion of the suspension.

By means of this instrument Coulomb was able to prove the two laws of electrical attraction:

1. The repulsion between two electrified bodies charged with the same electricity varies inversely as the square of the distance between them.

2. The attractions and repulsions vary in the ratio of

the products of the quantities of free electricity—that is to say, of the electric charges of the two bodies.

The action of points on metallic conductors in increasing the density of the charge at the point received the attention of Franklin. The following quotation from his "Experiments and Observations on Electricity, made at Philadelphia, 1774," describes Franklin's own experiments on this subject:

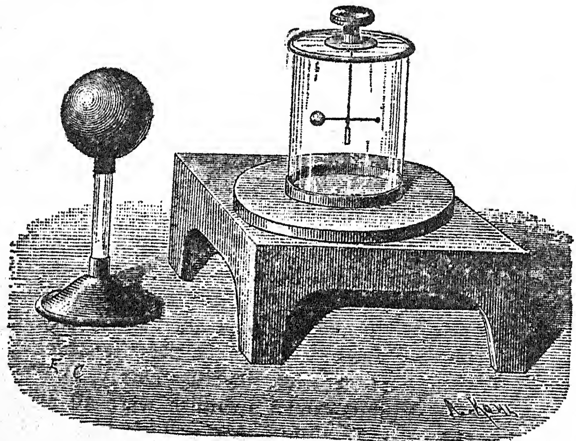


Fig. 5 —Coulomb's Method of Proving Electrostatic Laws.

"Place an iron shot of three or four inches diameter on the mouth of a clean, dry glass bottle. By a fine silken thread from the ceiling, right over the mouth of the bottle, suspend a small cork ball, about the bigness of a marble; the thread of such a length as that the cork ball may rest against the side of the shot. Electrify the shot, and the ball will be repelled to the distance of four or five inches, more or less, according to the quantity of electricity. When in this state, if you present to the shot the point of a long, slender, sharp bodkin, at six or eight inches dis-

tance, the repellency is instantly destroyed and the cork flies to the shot. A blunt body must be brought within an inch and draw a spark to produce the same effect.

"To prove that the electrical fire is drawn off by the point, if you take the blade of the bodkin out of the wooden handle and fix it in a stick of sealing-wax, and then present it at the distance aforesaid, or if you bring it very near, no such effect follows; but sliding one finger

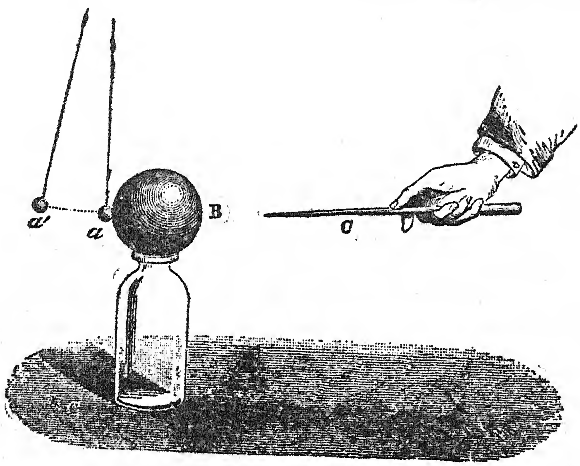


Fig. 6 —Franklin's Experiment on the Action of Points.

along the wax till you touch the blade, and the ball flies to the shot immediately. If you present the point in the dark you will see, sometimes at a foot distance and more, a light gather upon it, like that of a firefly or glowworm; the less sharp the point the nearer must you bring it to observe the light; and at whatever distance you see the light, you may draw off the electrical fire and destroy the repellency. If a cork ball so suspended be repelled by the tube, and a point be presented quick to it, 'tis surprising to

see how suddenly it flies back to the tube. Points of wood will do near as well as those of iron, provided the wood is not dry; for perfectly dry wood will no more conduct electricity than sealing-wax.

"It is calculated that the density of electricity at an

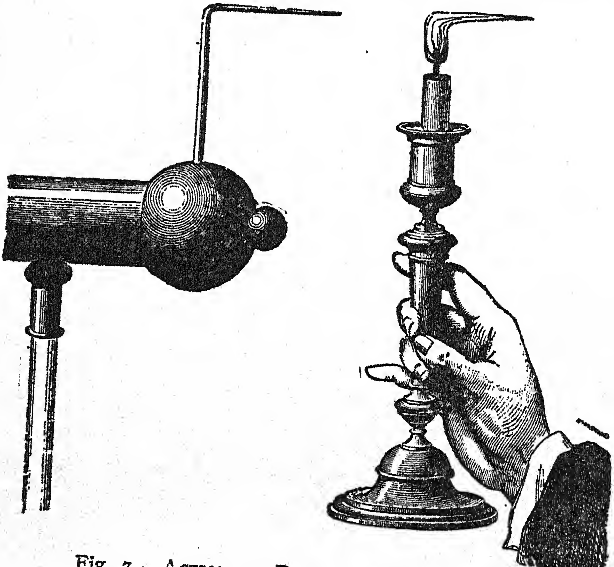


Fig. 7 —Action of Points: Electric Wind.

infinitesimally fine point would be infinitely great, since it is impossible to charge a pointed conductor in the air with electricity; this is proved by experiment. As fast as electrification is produced, it is given off the point into the air and disappears. When we examine the extremity of a point in the dark, there is seen a luminous crest. If, while the point is in communication with the source of electrification, one places one's hand before it, a draft

is at once perceptible, arising from the motions of the particles of air. This can be still better shown by holding a candle-flame in front of a long-pointed conductor. The electric wind is sufficient to bend the flame sharply down, or even to put it out.

"This movement of the air at the points on electrified conductors has always been attributed to the accumulation of electricity, which has been compared to a fluid; but the following explanation seems to us preferable, as it involves no hypothesis on the nature of electricity, and, besides, it is found to agree with known phenomena. The molecules of air, in contact with a point electrified to a great electric density, become charged with the same electrification as the conductor itself. Hence the nearest molecules are repelled and others fill their place, which become electrified in their turn, and so on. Hence the current of air, which only lasts as long as the electricity is being supplied. It can be stopped by putting a cap of sealing-wax over the point."

The explanation of the attraction of an electrified body for an unelectrified one was not well understood until the middle of the eighteenth century. John Canton, of Stroud, seems to have been the first to give the true explanation. His apparatus was similar to that shown in Fig. 8. If the sphere C be charged with a positive charge of electricity the end A of the cylinder, which is nearest to the sphere, will be charged negatively, the other end B will be charged positively. We can prove this if we bring an electrified pendulum near to each end in turn. Suppose the little ball to be charged positively, it is found to be attracted to the end A when brought carefully toward it, but when brought toward the end B it is repelled. The reverse would be the case if the sphere C were charged negatively.

It may be well here to point out the difference between a conductor and a dielectric, or non-conductor. A conductor merely connects different parts of the dielectric

which surrounds it and with which it is in contact. If, therefore, this dielectric be suddenly charged in one place this charge cannot remain at that place because it is in contact with the conductor, but must flow into the conductor, along it, and then out into the dielectric surrounding it, and this takes places at every point of contact between the conductor and the dielectric. The office of the conductor, then, is to distribute the charge to the dielectric. If the conductor be spherical in shape and there is no other charge near by, the dielectric will be charged uniformly

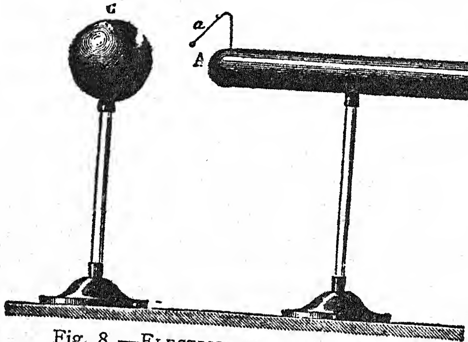


Fig. 8 —Electrification by Influence.

all about the sphere. If the conductor tapers to a point, the charge in the dielectric will be most intense about the point. Or if the charge about the sphere is influenced by a neighboring charge, the conducting sphere allows it to move as the charged body may dictate.

This principle of electrical influence was soon made use of in constructing a machine for the production of electric charges and which was the forerunner of the modern electrical influence machine. This was the electrophorus of Volta, who gave it the name of "perpetual electrophorus" because it preserves for a long time the charges that it has received.

"It consists of two parts: a cake of insulating material, such as resin, sulphur or india-rubber, cast into a wooden or metal tray, and a metal disk fixed to an insulating handle of glass or to silk cords. Frequently the disk is of smaller diameter than the cake, and sometimes it is made not of metal but of wood, covered on both edge and faces with tinfoil.

"To use the electrophorus, remove the metal disk and rub the insulating cake with flannel, woolen cloth or fur, best of all with a catskin. This produces negative electrification on the resinous cake. This you may prove if you bring your finger near the cake, for you will observe small sparks and crackling sounds. Now take the metal disk by the insulating handle and place it on the rubbed insulating cake.

"Now pause a moment: let us think what has happened in this action. While you were putting down the lid on the cake, even before it touched the cake, it was under influence. The cake is negative, hence as you hold the lid over it there will be a displacement and a rush of electricity in the lid, causing a positive charge to accumulate on the lower side, leaving the upper side negative. This effect will of course increase as the disk is lowered. It will be noticed that the metal dish in which the cake stands is also under influence; but this is of no importance.

"You must now touch with your finger the top of the lid. Your finger will also be under influence during this action, a + charge accumulating on its tip and then discharging itself with a small spark to fill up and neutralize the — charge on the top surface. Now lift up the lid by the handle. You will find that it is positively electrified, and you can carry away the charge and use it to give a big spark to any other conductor. You can then put the lid down again on the cake, touch it, lift it up again and take another spark as often as you please, the cake remaining all the time charged with its original

charge. The length of spark is roughly proportional to the size of the electrophorus.

"Mascart in his treatise says that Lichtenberg constructed an electrophorus with a cake six feet across and the disk was five feet across, and the sparks drawn from it fourteen to sixteen inches long. Another very large electrophorus was made by Kleindworth for the University of Göttingen; the cake of resin was 2.25 meters in diameter and the conducting disk 2 meters.

"The cake sometimes preserves its charge for months, if it be kept in a cupboard where the air is perfectly dry. We have said that the insulating cake of the electrophorus is made of resin, sulphur or india-rubber. All good insulators can be used; mixtures of these substances are generally used in order to make the cake less brittle."

A short description of the principal static machines which have been developed is taken from Professor S. P. Thompson's 'Elementary Lessons in Electricity and Magnetism.'

"For the purpose of procuring larger supplies of electricity than can be obtained by the rubbing of a rod of glass or shellac, electric machines have been devised. All electric machines consist of two parts, one for producing, the other for collecting, the electric charges. Experience has shown that the quantities of + and — electrification developed by friction upon the two surfaces rubbed against one another depend on the amount of friction, upon the extent of the surfaces rubbed, and also upon the nature of the substances used.

"The earliest form of electric machine was devised by Otto von Guericke of Magdeburg, and consisted of a globe of sulphur fixed upon a spindle, and pressed with the dry surface of the hands while being made to rotate; with this he discovered the existence of electric sparks and the repulsion of similarly electrified bodies. Sir Isaac Newton replaced Von Guericke's globe of sulphur by a globe of glass. A little later the form of the machine was im-

proved by various German electricians; Von Bose added a collector or "prime conductor," in the shape of an iron tube, supported by a person standing on cakes of resin to insulate them, or suspended by silken strings; Winckler of Leipzig substituted a leathern cushion for the hand as a rubber; and Gordon of Erfurt rendered the machine more easy of construction by using a glass cylinder instead of a glass globe. The electricity was led from the excited cylinder or globe to the prime conductor by a metallic chain which hung over against the globe. A pointed collector was not employed until after Franklin's famous researches on the action of points. About 1760 De la Fond, Planta, Ramsden and Cuthbertson constructed machines having glass plates instead of cylinders. All frictional machines are, however, now obsolete, having in recent years been quite superseded by the modern influence machines.

"The cylinder electric machine consists of a glass cylinder mounted on a horizontal axis capable of being turned by a handle. Against it is pressed from behind a cushion of leather stuffed with horsehair, the surface of which is covered with a powdered amalgam of zinc or tin. A flap of silk attached to the cushion passes over the cylinder, covering its upper half. In front of the cylinder stands the "prime conductor," which is made of metal, and usually of the form of an elongated cylinder with hemispherical ends, mounted upon a glass stand. At the end of the prime conductor nearest the cylinder is fixed a rod bearing a row of fine metallic spikes, resembling in form a rake; the other end usually carries a rod terminated in a brass ball or knob. When the handle is turned the friction between the glass and the amalgam-coated surface of the rubber produces a copious electrical action, electricity appearing as a + charge on the glass, leaving the rubber with a — charge. The prime conductor collects this charge by the following process: The + charge being carried round on the glass acts inductively on the long insulated conductor,

repelling a + charge to the far end; leaving the nearer end — ly charged. The effect of the row of points is to emit a — ly electrified wind toward the attracting + charge upon the glass, which is neutralized thereby; the glass thus arriving at the rubber in a neutral condition ready to be again excited. This action of the points is sometimes described, tho less correctly, by saying that the points collect the + charge from the glass. If it is desired to collect also the — charge of the rubber, the cushion must be supported on an insulating stem and provided at the back with a metallic knob. It is, however, more usual to use only the + charge, and to connect the rubber by a chain to "earth," so allowing the — charge to be neutralized.

"The friction of a jet of steam issuing from a boiler, through a wooden nozzle, generates electricity. In reality it is the particles of condensed water in the jet which are directly concerned. Sir W. Armstrong, who investigated this source of electricity, constructed a powerful apparatus, known as the hydro-electrical machine, capable of producing enormous quantities of electricity, and yielding sparks 5 or 6 feet long. The collector consisted of a row of spikes, placed in the path of the steam jets issuing from wooden nozzles, and was supported, together with a brass ball which served as prime conductor, upon a glass pillar."

After the invention of the electrophorus by Volta, the idea naturally suggested itself of performing mechanically the several operations of bringing the plate near the charged bed, of touching its upper side, and of removing it to a large metallic body where the charge could be stored. One of the first of these mechanical arrangements was the revolving doubler of Nicholson, invented in 1788, consisting of a revolving apparatus in which an insulated carrier can be brought into the presence of an electrified body, there touched for an instant while under influence, then carried forward with its acquired charge toward an-

other body, to which it imparts its charge, and which in turn acts inductively on it, giving it an opposite charge, which it can convey to the first body, thus increasing its initial charge at every rotation.

"In the modern influence machines two principles are embodied: (1) The principle of influence, namely, that a conductor touched while under influence acquires a charge of the opposite kind; (2) the principle of reciprocal accumulation. This principle must be carefully noted. Let there be two insulated conductors A and B electrified ever so little, one positively, the other negatively. Let a third insulated conductor C, which will be called a carrier, be arranged to move so that it first approaches A and then B, and so forth. If touched while under the influence of the small positive charge on A it will acquire a small negative charge; suppose that it then moves on and gives this negative charge to B. Then let it be touched while under the influence of B, so acquiring a small positive charge. When it returns toward A let it give up this positive charge to A, thereby increasing its positive charge. Then A will act more powerfully, and on repeating the former operations both B and A will become more highly charged. Each accumulates the charges derived by influence from the other. This is the fundamental action of the machines in question. The modern influence machines date from 1860, when C. F. Varley produced a form with six carriers mounted on a rotating disk of glass. This was followed in 1865 by the machine of Holtz and that of Toepler, and in 1867 by those of Lord Kelvin (the "replenisher" and the "mouse-mill"). The latest forms are those of Mr. James Wimshurst."

At the present time these machines are used to a limited extent as a source of high voltages for such work as operating vacuum tubes, X-ray apparatus, and the like; but their uncertainty of action, small power and the irregularity of their discharge make the high-tension transformer or Ruhmkorf coil preferable.

Cuneus, a pupil of Muschenbroek, a celebrated physicist of the eighteenth century, was one day trying to electrify some water in a wide-necked bottle. For this purpose he held the bottle in one hand, after having placed in the bottle a metal rod connected to the machine. When he thought the water was sufficiently electrified, he tried to remove the iron rod with one hand without loosing his hold of the bottle with the other hand. He received a shock that surprised him. Muschenbroek repeated Cuneus' experiment, but the shock that he received in his arms, shoulders and chest was so great that he lost consciousness and was so frightened that in writing to Réaumur about this then new discovery, he wrote that for nothing in the world, not even for the crown of France, would he go through it again. But some other physicists were less fearful. Allaman, Lemoinnier, Winckler and the Abbé Nollet varied the experiment in all sorts of ways, and so a new piece of apparatus was added to electrical science. This apparatus, called the Leyden jar, is named after the place where the experiment was first performed in 1746.

The Leyden jar is only a form of electric condenser, the essential properties of which have already been explained in connection with Maxwell's theory.

It is again to Franklin that science is indebted for an experiment which shows where the charge in such a jar resides. Franklin constructed a Leyden jar having both internal and external metallic coatings removable. Having fitted them to the jar, he connected the inner coating with an electrical machine and the outer coating with the earth and charged the jar in the usual manner. He then separated the metallic coatings and the jar, and examining each one for electrification, he found the metallic coatings practically unelectrified, while the glass jar proved to be highly electrified. Upon replacing the coatings in the jar, he was able to obtain a bright spark, just as tho the coatings had not been removed. This experiment clearly proved that the important part of such a Leyden jar or condenser

was the glass or dielectric and that the function of the conducting coatings was merely to spread the charge over the glass. Taking such a view, it will be readily seen that the larger the jar, the greater is the quantity of electricity which may be stored therein. Large jars are, however, often inconvenient to handle, so that a 'battery' of such jars is used having their inner coatings all connected together to form one large coating, and the outer ones similarly connected. Fig. 10 shows such a battery, the outer coatings being connected by the tinfoil lining of the box.

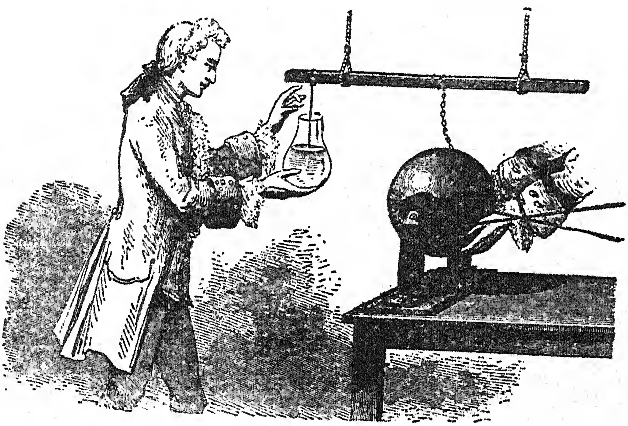


Fig. 9 —EXPERIMENT OF CUNEUS: THE LEYDEN JAR.

From time to time it has been attempted to use for the dielectric materials other than glass, and thousands of condensers using paraffined paper are in use on modern telephone and telegraph circuits. Larger condensers are used on power circuits. None of these other materials is, however, as satisfactory as glass, being liable to be disrupted if the pressure of the charge is too great. The opportunities for using condensers to advantage are rapidly

Cuneus, a pupil of Muschenbroek, a celebrated physicist of the eighteenth century, was one day trying to electrify some water in a wide-necked bottle. For this purpose he held the bottle in one hand, after having placed in the bottle a metal rod connected to the machine. When he thought the water was sufficiently electrified, he tried to remove the iron rod with one hand without loosing his hold of the bottle with the other hand. He received a shock that surprised him. Muschenbroek repeated Cuneus' experiment, but the shock that he received in his arms, shoulders and chest was so great that he lost consciousness and was so frightened that in writing to Réaumur about this then new discovery, he wrote that for nothing in the world, not even for the crown of France, would he go through it again. But some other physicists were less fearful. Allaman, Lemoinnier, Winckler and the Abbé Nollet varied the experiment in all sorts of ways, and so a new piece of apparatus was added to electrical science. This apparatus, called the Leyden jar, is named after the place where the experiment was first performed in 1746.

The Leyden jar is only a form of electric condenser, the essential properties of which have already been explained in connection with Maxwell's theory.

It is again to Franklin that science is indebted for an experiment which shows where the charge in such a jar resides. Franklin constructed a Leyden jar having both internal and external metallic coatings removable. Having fitted them to the jar, he connected the inner coating with an electrical machine and the outer coating with the earth and charged the jar in the usual manner. He then separated the metallic coatings and the jar, and examining each one for electrification, he found the metallic coatings practically unelectrified, while the glass jar proved to be highly electrified. Upon replacing the coatings in the jar, he was able to obtain a bright spark, just as tho the coatings had not been removed. This experiment clearly proved that the important part of such a Leyden jar or condenser

was the glass or dielectric and that the function of the conducting coatings was merely to spread the charge over the glass. Taking such a view, it will be readily seen that the larger the jar, the greater is the quantity of electricity which may be stored therein. Large jars are, however, often inconvenient to handle, so that a 'battery' of such jars is used having their inner coatings all connected together to form one large coating, and the outer ones similarly connected. Fig. 10 shows such a battery, the outer coatings being connected by the tinfoil lining of the box.

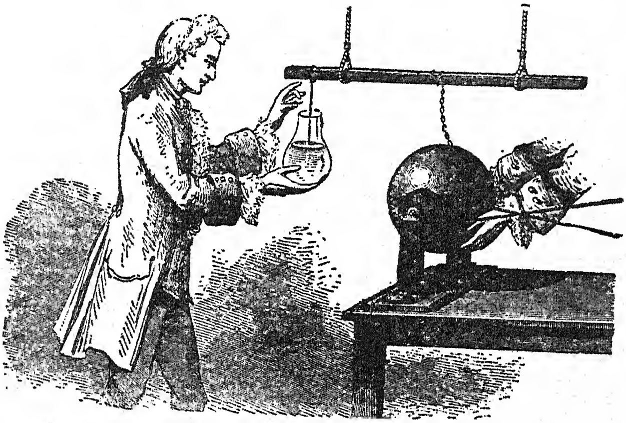


Fig. 9 —EXPERIMENT OF CUNEUS: THE LEYDEN JAR.

From time to time it has been attempted to use for the dielectric materials other than glass, and thousands of condensers using paraffined paper are in use on modern telephone and telegraph circuits. Larger condensers are used on power circuits. None of these other materials is, however, as satisfactory as glass, being liable to be disrupted if the pressure of the charge is too great. The opportunities for using condensers to advantage are rapidly

increasing at present and considerable energy is being directed toward their development. The desirable qualities of such a condenser are that its dielectric should be capable of containing a very large charge, that it should stand very high electric pressure without disruption, and that its coatings should be in the most intimate contact with the

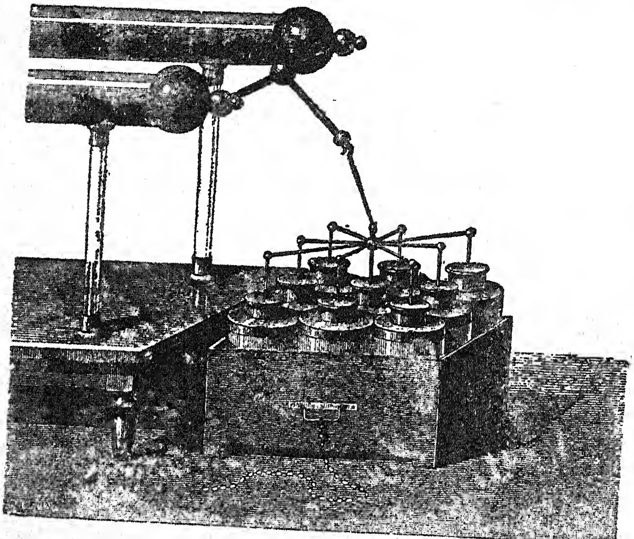


Fig. 10.—Battery of Leyden Jars.

dielectric. In some recent condensers, made in Switzerland, the metal coatings are made by chemically depositing silver upon the inner and outer surfaces of the glass.

The ancients, who knew nothing of electricity, could not conceive of thunder as anything but the result of a purely mechanical shock. Seneca, speaking of the fact that two hands struck together produced a loud noise, concluded from that that the collision of two enormous clouds

ought to sound with a very great crash. Again, he compares thunder, "the sound of which is very sharp, even penetrating, to the noise made by the bursting of a bladder on a person's head." Lucretius also explains thunder by the shaking of the clouds or their tearing asunder.

The identity of lightning with electricity was first shown by Benjamin Franklin in a paper published in 1749, two years before his experiments with the storm clouds. At that epoch he had just recognised the power of points. Two ingenious experiments in which this power was put into play furnished him with a new analogy and suggested to him to verify by the storm clouds the truth of his conjectures. Having suspended by silk threads to the ceiling of his room a tube of gilt paper, 10 feet in length and a foot in diameter, Franklin charged it with electricity. Then, presenting to the tube, at the distance of a foot, the point of a needle, the tube was instantly discharged; if, on the contrary, he presented to it a blunt body, an iron bolt or punch rounded at the end, he found it was necessary to put it within three inches before it could cause the discharge, which then, he said, took place with a sudden crackling. Suspending in the same way some great brass scales, the pans of which were supported by silk cords a foot from the floor, he electrified one of the pans. The twisting of the suspending cord caused the scales to turn; he placed the iron punch underneath, below a point of the circumference described. When the pan which was electrified passed over it, it lowered itself, came in contact with it and thus discharged itself. But if the end of the punch was furnished with a needle, the point uppermost, the pan passed above it without approaching, and the discharge took place silently, or if in its course the pan had come near enough for a spark to strike, it could not, because it would have been discharged beforehand.

"Now," says Franklin, " if the fire of electricity and that of lightning be the same, as I have endeavored to show at large in a former paper, this pasteboard tube and

these scales may represent electrified clouds. If a tube only 10 feet long will strike and discharge its fire on the punch at two or three inches distance, an electrified cloud of perhaps 10,000 acres may strike and discharge on the earth at a proportionately greater distance. The horizontal motion of the scales over the floor may represent the motion of the clouds over the earth and the erect iron punch a hill or high building, and then we see how electrified clouds passing over hills or high buildings at too great a height to strike may be attracted lower till within their striking distance. And lastly, if a needle fixed on the punch with its point upright, or even on the floor below the punch, will draw the fire from the scale silently at a much greater than the striking distance, and so prevent its descending toward the punch; or if in its course it would have come nigh enough to strike, yet being deprived of its fire it cannot, and the punch is thereby secured from the stroke.

"I say, if these things are so, may not the knowledge of this power of points be of use to mankind in preserving houses, churches, ships, etc., from the stroke of lightning by directing us to fix on the highest parts of those edifices upright rods of iron made sharp as a needle, and gilt to prevent rusting, and from the foot of those rods a wire down the outside of the building into the ground, or down round one of the shrouds of the ship, and down her side till it reaches the water? Would not these pointed rods probably draw the electrical fire silently out of a cloud before it came nigh enough to strike, and thereby secure us from that sudden and most terrible mischief?"

And thus it is that this discovery of Franklin's has been the means of saving much property from destruction. It is only of recent years that much has been added to the knowledge of the action of lightning rods and of their proper design and application. Hertz's experiments in electrical oscillations and the proof that lightning discharges were also oscillatory in their character, enabled

us to gain a better understanding of how to handle these tremendous discharges. It is now known that lightning discharges have a frequency of oscillation of about 500,-000 periods per second.

A recent and most beautiful application of condensers to the conduction of these lightning discharges to earth may not be out of place here. If a lightning discharge strikes an electric line in its course to earth it may find it easier to pass back to the generator at the power station, jump through the insulation to the frame and then to the earth, than to leap over the insulators and down the pole to the earth; the result being to destroy the generator. If, however, condensers are connected at various points along the line, it may be well to see what should happen.

Every time that a condenser is charged and discharged a current flows through the wire leading to it, one way on charging, the other on discharging. If this succession of charges and discharges takes place slowly, only a small amount will flow into and out of the condenser, but if it takes place rapidly the current is proportionately increased without the pressure being any higher. Suppose such condensers to be connected on a line in which the current has a frequency of 60 oscillations or cycles per second: a small current will then flow continually. This current is of such a character that it does not mean a waste of power—but this is too advanced to be here explained. If, however, a lightning discharge having a frequency of 500,000 per second strikes the line, it will pass readily to earth through the condensers instead of disrupting the insulation of the generators, the condensers being able to pass $\frac{500000}{60}$ as much current as would be passed from the line. There is still much to be learned of electrical disturbances in the atmosphere and little is yet known of the causes producing them. It is a field of vast possibilities and one whose study may result in giving Man a partial control over atmospheric conditions.

CHAPTER III

FUNDAMENTAL DISCOVERIES

THERE are in all sciences some discoveries which seem to open vast fields for exploration, and which appear suddenly to increase the power of mankind. In electrical science the benefits conferred by the discoveries of Volta and Galvani, Davy, Arago, Ampere, Faraday, Seebeck, Maxwell and Hertz are only just beginning to be realized. Volta and Galvani started the investigation of electric currents, and to-day the earth is full of applications of them, each one the servant of a human brain. Each day sees a new device based upon them, and each application presents them in a new light, which again leads to another useful appliance of the principles involved.

One hundred years ago men were not so well organized for scientific research as they are at present, and it may seem strange that such a simple discovery as electromagnetic induction should have taken so long to develop after the production of electric currents. It must be remembered, however, that organization was loose, not bound tightly together as it is now, when mankind is, as it were, united into one large concentrated brain. If a discovery is made at the present time the whole world knows of it in a few days, and thousands of men stand ready to apply it to all kinds of industries; and many men can bring their vast experience to the immediate aid of the discoverer, so that the discovery is quickly perfected. All this power of self-improvement is owed, however, to those whose

works have united men so closely. Scientific research has developed into a business. Large companies have gathered together the best brains of the world, money and conveniences are placed at their disposal, the needs of industry are presented to them and are quickly filled. The scientific brain is kept in constant touch with the wants of life, and there is at last accomplished that union of the scientist and the man of the world—the one with needs, the other with the means of fulfilling them—that was lacking in the earlier days.

There are, in general, two classes of scientists. One is possessed of a mathematical mind, delighting in the abstract solution of a problem and caring not whether the result turns out one way or another. He is concerned rather with the proof of the similarity of processes than with any difference of detail. To the man with the mechanical mind, however, the detection of differences is all-important. He finds his pleasure in observing differences in phenomena by the process of experiment, and his whole idea is to obtain a definite and useful result. Both classes of men are necessary. Maxwell developed a beautiful mathematical theory of great comprehensiveness, but the proofs waited for the experimental demonstrations of Hertz. The groundwork of the science is, however, usually developed through that property of so few minds—the power of observation.

The discovery of the electric current was an event. Galvani, an eminent doctor and professor of anatomy at the University of Bologna, was, one evening in the year 1780, busy in his laboratory, with some friends, making experiments relating to a nervous fluid in animals. On a table, where there was an electric machine used for the experiments, there had been placed by chance some recently skinned frogs, intended to make broth of. "One of Galvani's assistants," says P. Sue in his 'Histoire du Galvanisme,' "casually put the point of his instrument near the internal crural nerves of one of the animals;

immediately all the muscles of the limbs seemed to be agitated with strong convulsions. Galvani's wife was present; she was struck with the novelty of the phenomenon; she thought she saw that it occurred just at the moment when a spark was taken from the electric machine. She warned her husband, who hastened to verify this curious fact, and he recognised that the muscular contractions of the frog took place, in fact, every time that a spark appeared, but ceased while the machine was at rest."

This observation was the beginning of many experiments with the doctor by which he tried to prove the identity of the nervous fluid of animals with the supposed electric fluid. In 1786 he again continued researches of this kind. "Being anxious one day," says A. Guillemin in his 'Electricity and Magnetism,' "to see whether the influence of atmospheric electricity on the muscles of frogs would be the same as that produced in machines, he had for that purpose hung up a number of skinned frogs' legs on the balcony of a terrace of his house. He hooked the hind legs to the iron of the balcony by a copper wire which passed under the lumbar nerves. Galvani remarked with surprise that every time that the feet touched the balcony the frogs' limbs were contracted with quick convulsions, tho at that moment there were no signs of a stormy cloud, and, therefore, no particular electric influence of the atmosphere."

These facts suggested to Galvani the idea that there existed an electricity belonging to animals, inherent in their organization; that this electricity, secreted by the brain, resides specially in the nerves, by which it is communicated to the entire body; "that the principal reservoirs of this electricity are the muscles, each fiber of which may be considered as having two surfaces, and possessing by that means the two electricities, positive and negative, each of them representing besides, so to speak, a small Leyden jar, of which the nerves are the conduc-

tors." Hence the comparisons he makes between the muscular contractions in frogs and other animals and the commotions produced by the discharge of a Leyden jar.

Alexander Volta, then Professor of Natural Philosophy at Pavia, repeated Galvani's experiments, but he very soon modified his explanations. According to Volta, the electricity developed was of the same nature as that which an electric apparatus produces. It is the contact between dissimilar metals which gives place to the production of electricity, one of the metals being charged with a positive, the other with a negative electrification; these charges combine in traversing the middle conductor of muscles and nerves. Then arose between the two celebrated philosophers a discussion, a struggle, honorable to both, and, above all, profitable to science, which thereby became enriched by a multitude of new facts. The invention of the marvelous apparatus which received the name of the Voltaic pile at last caused the theory of the professor of Pavia to prevail, tho Galvani's hypothesis on the existence of a sort of animal electricity is now recognised as partly true. On the other hand, Volta's ideas have been somewhat modified.

The outcome of these contentions was the invention of Volta's pile, first made in 1800. Here, for the first time, was produced a means of generating a steady and continuous flow of electric current. Volta's construction was as follows: Disks of copper, zinc and flannel were cut out and arranged in a pile in the order, copper, flannel, zinc, and this order was successively repeated, the flannel being first dipped in sulphuric acid so that its function was merely to connect the copper and zinc by the acid. This arrangement gave a feeble electromotive force between the elements of each set, which increased when one connection was made at the lower end of the pile and the other was moved toward the top. Volta's idea of the action of the pile was, however, not as it is known to-day. He believed that the source of the electromotive force was

at the contact of the copper and the zinc disks, and that the moistened cloth served merely as a means of connecting them, whereas the real seat of this force is at the contact of the acid with the zinc.

This discovery of Volta's was the starting point of many investigations, in which the metals and the liquids were tried in all sorts of combinations, many of which were quite successful, and soon batteries were developed which were capable of furnishing quite powerful currents. For sixty years these batteries were the only source of current available for conducting the brilliant experiments of that period.

As soon as a source of current was obtainable it was natural to ascertain the effects of this current on various bodies. One of the first of these was that of Carlisle and Nicholson, in 1800, on the decomposition of water. Having passed the current of a volatile pile, formed of disks of silver and zinc, through water, they noticed that at the end of the copper wire which came from the negative pole of the pile some gaseous bubbles were given off, which they ascertained to be hydrogen; the other wire became rapidly oxidized. On substituting for copper, platinum, which is not attacked by oxygen, bubbles of this latter gas were given off in the same way from the positive wire. That is to say, when two platinum wires were used, oxygen gas was given off in bubbles from the surface of the wire by which the current entered the water, and hydrogen gas was at the same time given off in bubbles from the surface of the wire by which the current left the water.

The next fact of great importance was brought to light twenty years after the discovery of Volta's pile by Oersted, professor in the University of Copenhagen. This accomplished savant found that the electric current acted on the magnetic needle. "For a long time," says Guillemin, " there had been a suspicion of the existence of a relation between magnetic phenomena and electricity; peo-

ple had remarked the occurrence of perturbations by the mariner's compass on ships struck by lightning, or when their masts presented the phenonemon known by the name of St. Elmo's fire. It was known that discharges of batteries of Leyden jars affected magnetic needles placed near the apparatus." But these facts only gave vague ideas on the relation mentioned above.

In 1820, the year after that in which Oersted made his discovery, Ampere studied and described the laws of this action, and showed besides that the currents themselves acted on currents, and later Arago, Davy and Sturgeon discovered the magnetizing of steel and soft iron under the influence of the current from a battery. The experiments of these men were so many points of departure for a multitude of new experiments which in a short time completely changed the aspect of this part of the science by showing that magnetism and electricity are different manifestations of the same cause.

Oersted expressed his discovery by saying that a current acts "in a revolving manner" on a magnetic needle. He does not, however, seem to have understood that the electric current carried about it a magnetic field, and that it was the mutual action of this field and of the magnetism in the needle that produced the deflection. Oersted expressed the law of the deflection as follows: When an electric current acts on the magnetic needle, the north pole of the needle is urged toward the left of the current.

Ampere was the first to use Oersted's discovery to measure the intensity of currents; but to Schweigger and to Poggendorf, working independently, is due the happy thought of multiplying the action of electricity on the magnetizing needle so as to detect the existence of the feeblest current. This instrument, then termed the multiplier, is now called the galvanometer, and its importance as a factor in the further development of the science is seldom appreciated. From this developed the Thomson galvanometer, in which the needles were made ex-

tremely small and light and having a mirror attached, upon which a beam of light was thrown, and the reflected beam was made to pass over a scale. The galvanometer was thereby furnished with a long weightless pointer, whereby the smallest motion of the needle was multiplied many times, and extremely small currents could be detected.

In September, 1820, a little while after the discoveries of Oersted and Ampere, Arago made the following experiment: He plunged into a mass of iron filings a copper wire which was connected to the two poles of a battery; on drawing out the wire, without interrupting the current, he found it to be covered over its whole surface with particles of filings arranged transversely. As soon as the current was broken the iron particles became detached from the copper and fell down. To assure himself that this was really temporary magnetism, and not the attraction of an electrified body for light bodies, he substituted for the iron filings a non-magnetic substance, such as copper dust or powdered glass, and found that the phenomenon did not take place. On placing needles of soft iron, and then of tempered steel, very near the copper wire and across it, he saw that the action of the current transformed them into magnetic needles, having their south poles always to the left of the current, a result in conformity with the earliest experiments of Oersted. Shortly afterward Arago and Ampere noticed that magnetism of iron or steel is developed much more energetically by placing the needle inside a spiral coil of wire through which the current flows. This was the origin of the electro-magnet which was later developed by Sturgeon and Henry.

The discovery of the greatest value to electrical science was that made by Faraday in 1831. He reasoned that if magnetism could be produced by the action of the electric current, the converse should also be true, and after some experimenting he was successful in demonstrating it. An interesting account of his experiments is given

below, being an extract from Professor Tyndall's 'Faraday as a Discoverer':

"In 1831 we have Faraday at the climax of his intellectual strength, forty years of age, stored with knowledge and full of original power. Through reading, lecturing and experimenting, he had become thoroly familiar with electrical science; he saw where light was needed and expansion possible. The phenomena of ordinary electric induction belonged, as it were, to the alphabet of his knowledge: he knew that under ordinary circumstances the presence of an electrified body was sufficient to excite, by induction, an unelectrified body. He knew that the wire which carried an electric current was an electrified body, and still that all attempts had failed to make it excite in other wires a state similar to its own. What was the reason of this failure?

"Faraday never could work from the experiments of others, however clearly described. He knew well that from every experiment issues a kind of radiation, luminous in different degrees to different minds, and he hardly trusted himself to reason upon an experiment that he had not seen. In the autumn of 1831 he began to repeat the experiments with electric currents which, up to that time, had produced no positive result. And here, for the sake of younger inquirers, if not for the sake of us all, it is worth while to dwell for a moment on a power which Faraday possesed in an extraordinary degree. He united vast strength with perfect flexibility. His momentum was that of a river, which combines weight and directness with the ability to yield to the flexures of its bed. The intentness of his vision in any direction did not apparently diminish his power of perception in other directions; and when he attacked a subject, expecting results, he had the faculty of keeping his mind alert, so that results different from those which he expected should not escape him through preoccupation.

"He began his experiments 'on the induction of electric

attractions and repulsions of electric currents. Magnetism had been produced from electricity, and Faraday, who all his life long entertained a strong belief in such reciprocal actions, now attempted to effect the evolution of electricity from magnetism. Round a welded iron ring he placed two distinct coils of covered wire, causing the coils to occupy opposite halves of the ring. Connecting the ends of one of the coils with a galvanometer, he found that the moment the ring was magnetized, by sending a current through the other coil, the galvanometer needle whirled round four or five times in succession. The action, as before, was that of a pulse, which vanished immediately. On interrupting the current, a whirl of the needle in the opposite direction occurred. It was only during the time of magnetization or demagnetization that these effects were produced. The induced currents declared a change of condition only, and they vanished the moment the act of magnetization or demagnetization was complete.

The effects obtained with the welded ring were also obtained with straight bars of iron. Whether the bars were magnetized by the electric current, or were excited by the contact of permanent steel magnets, induced currents were always generated during the rise and during the subsidence of the magnetism. The use of iron was then abandoned, and the same effects were obtained by merely thrusting a permanent steel magnet into a coil of wire. A rush of electricity through the coil accompanied the insertion of the magnet; an equal rush in the opposite direction accompanied its withdrawal.

The precision with which Faraday describes these results and the completeness with which he defined the boundaries of his facts are wonderful. The magnet, for example, must not be passed quite through the coil, but only half through, for if passed wholly through the needle it is stopped as by a blow, and then he shows how this blow results from a reversal of the electric wave in the helix. He next operated with the powerful permanent magnet of

the Royal Society, and obtained with it, in an exalted degree, all the foregoing phenomena, and now he turned the light of these discoveries upon the darkest physical phenomenon of that day.

Arago had discovered in 1824 that a disk of non-magnetic metal had the power of bringing a vibrating magnetic needle suspended over it rapidly to rest, and that on causing the disk to rotate the magnetic needle rotated along with it. When both were quiescent, there was not the slightest measurable attraction or repulsion exerted between the needle and the disk; still, when in motion the disk was competent to drag after it not only a light needle, but a heavy magnet. The question had been probed and investigated with admirable skill by both Arago and Ampere, and Poisson had published a theoretic memoir on the subject; but no cause could be assigned for so extraordinary an action. It had also been examined in this country by two celebrated men, Mr. Babbage and Sir John Herschel; but it still remained a mystery. Faraday always recommended the suspension of judgment in cases of doubt.

"I have always admired," he says, "the prudence and philosophical reserve shown by M. Arago in resisting the temptations to give a theory of the effect he had discovered, so long as he could not devise one which was perfect in its application, and in refusing to assent to the imperfect theories of others." Now, however, the time for theory had come. Faraday saw mentally the rotating disk, under the operation of the magnet, flooded with his induced currents, and from the known laws of interaction between currents and magnets he hoped to deduce the motion observed by Arago. That hope he realized, showing by actual experiment that when his disk rotated currents passed through it, their position and direction being such as must, in accordance with the established laws of electromagnetic action, produce the observed rotation.

Introducing the edge of his disk between the poles of

the large horseshoe magnet of the Royal Society, and connecting the axis and the edge of the disk each by a wire with a galvanometer, he obtained, when the disk was turned round, a constant flow of electricity. The direction of the current was determined by the direction of the motion, the current being reversed when the rotation was reversed. He now states the law which rules the production of currents in both disks and wires, and in so doing uses for the first time a phrase which has since become famous. When iron filings are scattered over a magnet, the particles of iron arrange themselves in certain determined lines called magnetic curves.

In 1831 Faraday for the first time called these curves "lines of magnetic force," and he showed that to produce induced currents neither approach to nor withdrawal from a magnetic source, or center, or pole was essential, but that it was only necessary to cut appropriately the lines of magnetic force. Faraday's first paper on Magneto-electric Induction, which is here briefly condensed, was read before the Royal Society on the 24th of November, 1831.

Faraday delighted in investigation for the sake of the processes themselves. He had no inclination to follow up his discoveries with their practical application. The attitude of his mind is best described in his own words. "I have rather," he writes in 1831, "been desirous of discovering new facts and new relations dependent on magneto-electric induction than of exalting the force of those already obtained, being assured that the latter would find their full development hereafter."

CHAPTER IV

ELECTRO-MAGNETIC MACHINERY

As PREVIOUSLY related, the relations of electricity and magnetism were established by the investigations of Oersted, Ampere, Arago, Faraday, and others; but the one to whom the most credit is due is Faraday. He not only made discoveries of the greatest importance, but he followed up these discoveries with such true explanations of their principles that these explanations have become the basic laws of electro-magnetic induction. Faraday, however, did not care to make practical use of his discoveries, being sure that others would do so. What were some of these discoveries which have been of such great value to succeeding generations? One of them was a modification of Arago's experiment in which Faraday rotated a metallic disk between the poles of a magnet, and, by connecting one wire to the shaft of the disk and another in rubbing contact with its rim, produced a steady deflection on the galvanometer. This was really the first electro-magnetic generator. Here Faraday produced a continuous current without that drawback to direct current machines of the present day—the commutator.

It has from time to time been attempted to build machines based on Faraday's experiment, but the voltage generated was not sufficient for practical purposes. Recently, however, owing to the introduction of the steam turbine with its high speed, generators have been built of large powers and voltages of 600 or more which are based

on this principle. In this experiment of Faraday's, then, was the beginning of the modern electric generator with its almost unlimited power of changing mechanical into electrical energy or vice versa. Faraday did not at first use an electro-magnet, but in his first public demonstrations used a very powerful permanent magnet. Faraday made many other experiments in the induction of currents, culminating in the production of an apparatus known as Faraday's ring, the ancestor of the modern alternating current transformer.

"The first development of Faraday's discovery," says Henry Morton in his 'Electric Lighting,' "was made by Pixii, of Paris, who in 1832 constructed an apparatus in which a large steel magnet was rotated so that its poles continuously and successively swept past those of an electro-magnet, or U-shaped bar of soft iron whose ends were surrounded with coils of copper wire. This motion generated in the copper wire rapidly alternating electric currents, which were 'commuted' or made to pass out of the machine in a constant direction by a simple 'commutator' on the axis of the revolving magnet, which shifted the connections each time the direction of the current was changed.

"In the machine of Pixii, near the top, are seen the copper-wire coils wound on cores of soft iron, like thread on a spool. Immediately below these is the permanent magnet, of a U shape and so supported that it can be rapidly rotated about a vertical axis midway between its poles, so that each pole is caused to approach, pass and recede from in succession each of the iron cores of the coils. Immediately below the bend of the U-magnet are the commutator segments, pressed upon by the contact brushes, and below these again is the gearing by which the magnet is made to rotate. Machines operating on the same principle, but varying in construction (as, for example, by rotating the electro-magnet or coils of copper wire while the steel permanent magnet remained stationary),

were brought out by Saxton, of Philadelphia, in 1833; by Clark, of London, in 1834; and by Page, of Washington, in 1835. None of these machines, however, was of sufficient size to be available for the production of a practical electric light, altho they all exhibited a capacity for this effect on a minute scale.

"The first magneto-electric machine of a magnitude sufficient to operate a practical electric lamp was that pro-

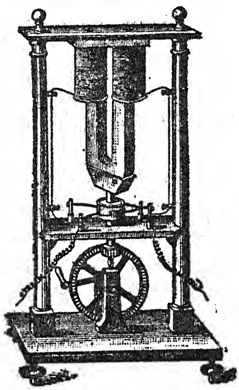


Fig. 11 —Pixit's Magneto-electric Machine, 1832.

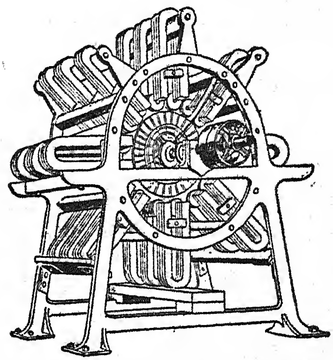


Fig. 12 —An Alliance Dynamo Used in the South Foreland Lighthouse, 1858.

duced by the united labors of M. Nollet, Professor of Physics at the Military School of Brussels, and his assistant constructor, Joseph van Malderen, under the auspices of a corporation composed of French and English capitalists and known as the 'Alliance Company.' Strange to say, this machine was built with the absurd object of using it to decompose water and employ the resulting gases in the production of light."

This machine, with some modifications by Mr. Holmes, of England, was, under the superintendence of Faraday

himself, introduced into two of the English lighthouses, at South Foreland and at Dungeness. Its preliminary trial was made in 1857. The electric light was first thrown over the sea from the South Foreland on the evening of December 8, 1858, and from Dungeness on the 6th of June, 1862. Fig. 12 shows in outline one of the Alliance machines, as modified by Mr. Holmes, which was long since put in operation at the South Foreland lighthouse. The outer framework supports twenty-four compound steel permanent magnets, and a drum inside carries thirty-two armatures or spools of copper wire wound on iron cores. As these pass from pole to pole between the magnets currents are developed which are carried off by commutators on the farther end of the shaft, not shown.

The electric light was not introduced into the French lighthouses until December 26, 1863, when it was installed at La Heve, near Havre. It was also used for lighting works of construction, such as the Cherbourg Docks, and on some vessels, for example, on the Lafayette and the Jerome Napoleon. Altho Faraday lived to see the little spark which he had developed from a magnet and coil of wire in his laboratory grow into these magnificent illuminators of sea and land, it was not until after many years and numerous new developments that the electric light approached the commercial utility which it to-day possesses. These Alliance machines, on account of their great size and multitude of parts, were very expensive. Thus the two machines placed in the Dungeness lighthouse, with their engines, appliances, and lamps or "regulators," cost £4,760, or nearly $24,000. The two located at Souter Point in like manner cost £7,000, or about $35,000, and the machines and accessories for the two lights at South Foreland cost £8,500, or about $42,500. The same characteristics caused them to be liable to accident and injury and costly in repairs. The world therefore waited for some further development before it could enjoy gen-

erally the advantages of electricity as a means of illumination.

The first of these came when Dr. Werner Siemens, of Berlin, constructed a machine in which the revolving coil or armature was made of the form shown in Fig. 13, and was entirely enclosed between the ends of the permanent magnets. To construct this armature a long, solid cylinder of soft iron is taken, and two deep grooves are cut on opposite sides through its entire length, so that its cross-section is such as appears at F in the accompanying figure. Insulated copper wire is then wound lengthwise in these grooves, its ends being united to the section x, y of the commutator. Journals on which this armature rotates are provided at either end, and at one end also a pulley by which it may be driven by a belt.

This armature secured a great concentration of action by bringing the revolving armature into a highly concentrated field of magnetic force and allowing it to have a very rapid angular velocity of rotation. But the chief value of this improvement consisted in its serving as a step toward another, which was most remarkable in its results and excited the liveliest interest all over the world when it was announced.

This next step was taken by Wilde, of Manchester. He took a small magneto-electric machine, such as had been constructed by Siemens, and carried the current from its commutator to the coils of very large electro-magnets, which constituted the field magnets of a similar machine, which, however, differed from the other, or Siemens machine, both in size and in having its field constructed of electro-magnets in place of permanent magnets. Fig. 14 shows such a combination, in which the first or small magneto-electric machine is mounted on the top of the other, and sends the current from its commutator through the coils of the electro-magnet below, between whose expanded poles another Siemens armature is made to revolve. Under these circumstances the current developed

in the armature of the upper machine by its permanent steel magnets will develop a more than tenfold greater magnetic force in the poles of the electro-magnet of the lower machine; and the second armature, rotating in this powerful magnetic field betwen the poles of this large electro-magnet, will develop a more than tenfold greater current than that of the smaller machine. This method of multiplying or creating magnetic force was a wonderful

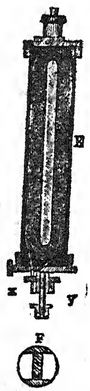


Fig. 13 —SIEMENS' SHUTTLE ARMATURE.

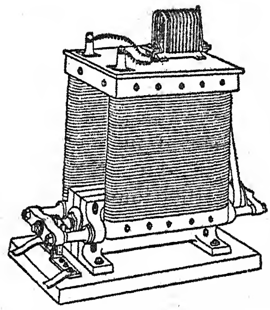


Fig. 14 —THE WILDE DYNAMO.

discovery, and, combined with the use of electro-magnets in place of permanent magnets for the production of the magnetic field, gave an important increase in power and efficiency to the machine; for as compared with permanent magnets the power of electro-magnets is vastly greater.

This advance, made by Wilde on April 13, 1866, was quickly followed by another, made almost simultaneously in Europe by Varley, Siemens, and Wheatstone, and nearly a year earlier in this country by Mr. M. G. Farmer,

whose work in another department of electric lighting is to be treated in more detail farther on. This development may be indicated by the term "self-exciting," and consisted in the discovery that if the commutator is so connected with the coils constituting the field magnets that all or a part of the current developed in the armature will flow through these coils, then all permanent magnets may be dispensed with, and the machine will excite itself or charge its own field magnets without the aid of any charging or feeding machine.

There is in all iron, unless special means have been taken to remove it, a little magnetic force. This small magnetic force, called "residual magnetism," in the iron cores of the field magnets will produce a little current in the armature when it is revolved. This current flowing through the coils of the field magnets will increase their magnetic force, and thus cause them to develop more current in the armature, which in turn, flowing through the coils of the field magnets, will further increase their magnetic force, and so on until maximum, determined by the structural conditions of the machine and the amount of driving force applied to the pulley of the armature, is reached. In practice such machines are each complete within themselves. When started they develop for a few moments only very feeble currents; but within a few seconds they "wake up" by degrees, and reach their maximum in less time than it takes to read this paragraph.

One other radical improvement in dynamo-electric machines remains to be recorded, namely, that due to the French inventor Gramme. The essence of this lay in the structure of the armature. While previous to Gramme all armatures had been constructed either like spools of cotton or like balls of yarn wound on blocks, he made his armature by starting with an iron ring (itself consisting of a coil of soft iron wire), and winding the copper wire on this by passing the end of the wire again and again through the ring. A Gramme armature ring, cut and bent

out partly, and with some of its copper coils removed, is shown in Fig. 15. The cut ends of the iron wires constituting the ring-core are shown at A, and B shows a portion of the copper-wire coils wound around this ring-core. The copper wire is continuous throughout as regards its electric connection, but at frequent intervals a loop of this

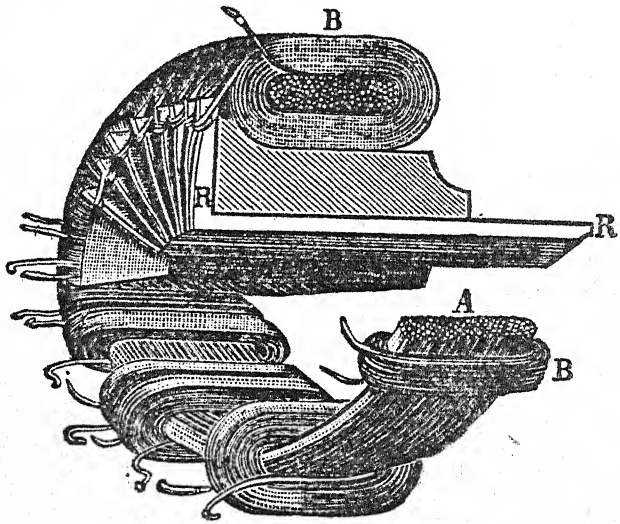


Fig. 15 —Section of a Gramme Ring Armature.

wire is carried out and attached to a segment of the commutator.

This armature being rotated in a magnetic field—*i.e.*, between the poles of powerful field magnets—tends to deliver a substantially continuous current to "brushes" touching the commutator segments at points midway between the poles of the field magnets. It will be remembered that the iron ring constituting the core of the

Gramme armature was made of iron wires, and not of a solid piece or ring of iron. The object of this was to prevent the formation of electric currents in this ring-core itself, commonly called Foucault currents, which would be a cause of inconvenience by heating the armature and of loss by wasting energy in the useless production of this heat. The Siemens armature had no such provision, and accordingly very serious difficulties were experienced in the running of machines using such armatures by reason of the intense heat there produced. Arrangements were in fact made in many machines to relieve this symptom by running cold water through the armature, made hollow for that end; but this did not cure the disease or prevent the loss of efficiency caused by the conversion of the driving energy into useless heat in place of useful current. The desirable end was, however, soon secured by "laminating the armature core"—that is, making it up out of a great number of thin sheets of iron insulated from each other and held together by one or more bolts. The merit of this invention appears to have ben assigned by the United States Patent Office to Edward Weston, September 22, 1882.

A Weston generator of about 1890 is shown in Fig. 16. In comparing this with a modern machine, the most marked feature is the large and heavy field magnet. Edison's first generators, of which some are still in operation, also contain these tremendous field magnets. These large field magnets were made necessary because the idea of embedding the wires in the armature in slots had not yet been originated. The fields were therefore made powerful in order to force the requisite magnetic flux across the large air gap into the armature.

By the later improvement of embedding the wires in slots in the armature, the air gap was much reduced and the fields made proportionately lighter. This decreased very considerably both the weight and cost of the machine.

A change in the design of direct current generators of

considerable importance was occasioned by the desirability of connecting them to slow-speed engines of the Corliss type—engines of low steam consumption. To accomplish this many poles were arranged in a circular yoke, and these were called "multipolar" generators. Upon the introduction of the high-speed steam turbines, however, the number of poles was again decreased to two, four, or six,

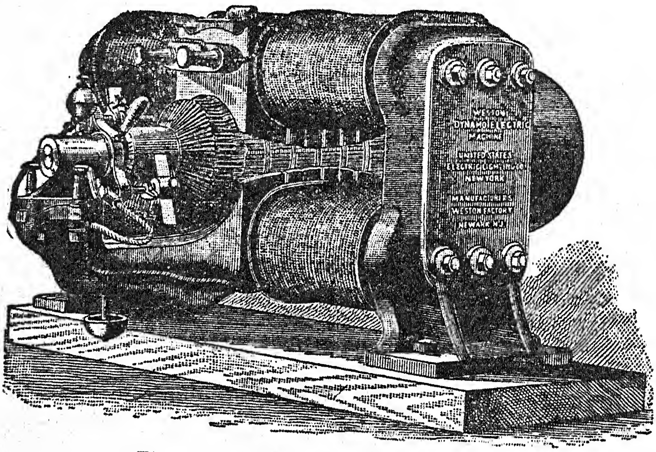


Fig. 16 —A Weston Dynamo of 1890.

and the weight of a machine of given power was greatly reduced. Herein lies one of the advantages of the steam turbine for driving generators.

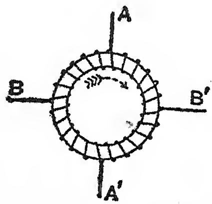
The dynamo is first of all a generator of alternating currents, and the commutator was added for the purpose of rectifying them. This commutator was always a source of trouble, mainly on account of sparking and the wearing away of the brushes and commutator surface. On the other hand, continuous currents are, in many cases, much easier to handle than alternating ones, and it was this fact

which caused so much effort to be spent on the development of direct current apparatus. Direct currents could be transmitted with less loss of voltage in the line and direct current motors were quite well developed before 1890. These two very important facts caused the direct current to reign supreme. In the latter part of the 80's, however, its overthrow began, and ever since it has gradually been declining before the advance of its more flexible rival—the alternating current. At that time Nikola Tesla took out patents covering the principles of the induction motor—a motor which, on account of its mechanical simplicity, rapidly found favor, altho inferior to the direct current motor in many respects. The fundamental principle of these motors lies in the production of a rotating magnetic field, which field drags along with it, at a somewhat slower speed, a cylindrical armature called the rotor.

An idea of how a rotating field is produced by the action of polyphase currents is given in Professor S. P. Thompson's 'Elementary Lessons in Electricity and Magnetism.' "It is obviously possible," he says, "by placing on the armature of an alternator two separate sets of coils, one a little ahead of the other, to obtain two alternate currents of equal frequency and strength, but differing in phase by any desired degree. Gramme, indeed, constructed alternators with two and with three separate circuits in 1878. If two equal alternate currents, differing in phase by one-quarter of a period, are properly combined, they can be made to produce a rotatory magnetic field. And in such a rotatory field conductors can be set rotating, as was first suggested by Baily in 1879.

"Consider an ordinary Gramme ring (Fig. 17) wound with a continuous winding. If a single alternating current were introduced at the points A A′ it would set up an oscillatory magnetic field, a N pole growing at A, and a S pole at A′, then dying away and reversing in direction. Similarly, if another alternate current were introduced at B B′

it would produce another oscillatory magnetic field in the B B′ diameter. If both these currents are set to work but timed so that the B B′ current is ¼ period behind the A A′ current, they will then combine to produce a rotatory magnetic field, tho the coil itself stands still. This is quite analogous to the well-known way in which a rotatory motion, without any dead points, can be produced from two oscillatory motions by using two cranks at right angles to one another, the impulses being given ¼ period one after the other. The above combination is called a diphase



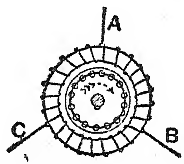


Fig. 17 —CONNECTIONS FOR PRODUCING A ROTATING FIELD FROM TWO-PHASE CURRENTS.

Fig. 18 —CONNECTIONS FOR PRODUCING A ROTATING FIELD FROM THREE-PHASE CURRENTS.

system of currents. If the B B′ current is ¼ period later than the A A′ current the rotation will be right-handed.

"Another way of generating a rotatory field is by a triphase system (or so-called 'dreh-strom') of currents. Let 3 alternate currents, differing from one another by ⅓ period (or 120°), be led into the ring at the points A B C. The current flows in first at A (and out by B and C), then at B (flowing out by C and A), then at C (out by A and B), again producing a revolving magnetic field. This is analogous to a 3-crank engine, with the cranks set at 120° apart."

One of the important features of these motors is their successful operation at high voltage—11,000 or more. Another feature is their mechanical simplicity, there being

no commutator, rings, brushes or other parts to collect dirt and thus interfere with the operation of the machine. As previously stated, alternators are usually wound to generate two or three phase currents, altho they may be built for other phases. In the last few years, however, the three-phase generator has practically controlled the field on account of the wide use of three-phase currents. Historically the generators have developed in the order of single, two, and three phase.

The first generators to come into commercial use were single-phase—*i.e.*, had a single winding in the armature. A notable instance of the use of these generators was the first plant of the Telluride Power Company in Colorado, where a single-phase generator was connected to a water wheel and the electrical energy developed again converted into mechanical energy by an exactly similar machine used as a motor. When an alternating current generator is used as a motor it is called a synchronous motor, for the reason that its speed must be absolutely synchronous with that of the generator. Alternating current generators are thus reversible in their action, just as are direct current generators. They are not, however, usually self-starting, but require auxiliary motors to bring them up to speed.

After the development of the induction motor—it being necessary to have polyphase currents for the production of the rotating magnetic field—two-phase generators came into use. Probably the largest of these are located in the first and second Niagara Falls power houses, where there are twenty-one, each one being of 3,750 kilowatts or 5,000 horse-power capacity. In transmitting this power to Buffalo, it is first changed to three-phase by a simple connection of transformers—known as Scott's connection—because 25 per cent. of copper is saved thereby. In the more recently constructed generators three-phase windings are almost exclusively used, principally because of the advantage of three-phase transmission. It is a notable fact, however, that these generators were used in the

Frankfort-Lauffen transmission of 1891 in Germany, transmission being effected, then as now, by three wires. These alternators are now built in sizes as large as 7,500 and 10,000 kilowatts, or 10,000 and 13,300 horse-power.

In 1893 the rotary converter was brought out. This machine is the connecting link between alternating and direct currents, usually serving to convert alternating into direct current, altho it may be used in the reverse way. In construction it is similar to a direct current generator, with the addition of collecting rings for the introduction of the alternating current. Many of the converters now in use are six-phase, the change from three to six phase being accomplished by the transformers used to reduce the voltage. These machines serve to connect the superior qualities of the alternating current for transmission purposes with the more perfect ones of the direct current motor for traction purposes. On account of the degree of perfection which has been attained recently with the alternating current motor, it would seem that the days of the rotary converters are numbered.

The induction coil and the alternating current transformer are founded on the same principles, but differ somewhat in the purposes to which they are applied. Each depends upon the fact that if the magnetic flux passing through a coil is changed in value, an electromotive-force will be set up in the coil which will be proportional to the rapidity of that change. There are several ways of producing the flux through the coil. One is by the introduction of a magnet into the coil, in which case the magnetic flux may be caused to change by moving the magnet in and out of the coil, there being established an electromotive-force in one direction upon its introduction, and in the reverse direction upon its withdrawal. Another method is to cause the flux created by another coil to pass through the first one and to vary this flux by changing the current in the second coil. The coil causing the flux is called the

primary, and that in which the electromotive-forces are set up, the secondary coil.

The best way of making the flux set up by the primary coil pass through the secondary coil is to wind the two coils on the same core. It will here be evident that an electromotive-force will be induced, not only in the secondary coil, but in the primary as well, since each turn of wire surrounding the changing magnetic flux is equally affected. This electromotive-force is called the electromotive-force of self-induction, and acts in such a way as to retard the establishment of a current in a coil, and to maintain it when it is attempted to stop it. In other words, it causes the circuit to act as tho it possessed inertia. From these statements it would appear, then, that the higher the electromotive-force which it is desired to set up, the more rapidly must the magnetic flux be changed and the greater must be its value. A flux withdrawn from a coil infinitely fast would produce an infinitely high electromotive-force, but this is no more possible than it is to stop a heavy fly-wheel instantly. Having now in mind what is desired in an induction coil, let us see how the various methods for producing these results gradually developed.

The credit for all discoveries in electromagnetic induction is usually given to Faraday. One should not, however, in this connection forget Professor Henry, whose discoveries were made without a knowledge of Faraday's works, and but a few months after them. Faraday discovered the effect of one coil upon another, but Henry was the first to discover the electromotive-force of self-induction, and published his discovery in 1832. In his first experiments Henry used copper tape or ribbon wound in the form of a spiral, and, upon passing a current through this spiral and suddenly interrupting it, he obtained a bright spark, and if the two ends of the coil were touched by the hands at the instant of break, a shock was felt. When the current was alternately made and interrupted

by rubbing one of the wires over a rough metal plate, vivid sparks were obtained. In 1836 the Rev. N. J. Callan, of Maynooth College, constructed an electromagnet with two separate insulated wires, one thick and the other thin, wound on the iron core together. The thick wire was copper, and through this the current was passed. The thin wire was iron, having one end attached to the thick winding. Upon making and breaking the current, he obtained severe shocks from the iron wire circuit. Later he extended his experiments by constructing a larger apparatus of sufficient power to kill small animals.

In 1837, Sturgeon, the inventor of the electromagnet, constructed a coil on Callan's plan, but of a shape resembling the wooden coil. He applied to his coils a make-and-break arrangement, consisting of a wire dipping in a mercury cup in one case and of a notched zinc disk in the other. He made experiments with solid iron cores, and noticed that when the interruptions of the current became too rapid, the effect was much diminished. He draws attention to the fact that G. H. Bachhoffner had tried a divided iron core and had observed that a bundle of fine iron wires used as a core gave far better shocks than when a solid iron bar was employed. Sturgeon therefore made use of the iron wire core in constructing his coils, one of which was exhibited to the London Electrical Society in August, 1837.

The next advance was made by Callan in September, 1837, when he constructed two coils, each with its primary and secondary windings separate. These coils he connected together with their primaries in parallel and their secondaries in series, so that the secondary electromotive-forces added together. He surmises that if a hundred such induction coils could be aranged with their secondaries in series and their primaries in parallel, it would be possible to have a shock equal to 100,000 or 200,000 single cells.

In 1838, Professor Page, of Washington, constructed a

coil closely resembling modern coils. The two windings were entirely separate and he used the iron wire core. In addition he made a very important improvement. It has been seen that the value of the electromotive-force depends upon the suddenness of the collapse of the magnetic flux. Page noticed that the spark produced in his mer-

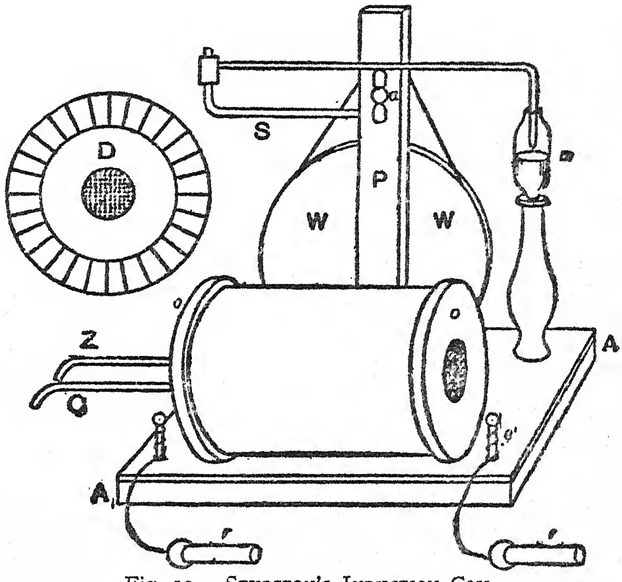


Fig. 19 —Sturgeon's Induction Coil.

cury contact breaker was quite prolonged, so that the current producing the flux in the core was not stopped as suddenly as it should be, and he conceived the idea of covering the mercury with oil or alcohol in order to suppress the spark, and this proved a valuable addition. This device was revived many years after by other inventors, particularly by Foucault. Page was the first to notice that

when a metallic sheath or tube is interposed between the primary and secondary circuits, it more or less annuls the action. Between 1838 and 1850 Page made many induction coils. With one of his coils he found he could obtain sparks ½ inch long in air. He also noticed the effect of rarefying the air upon the length of the discharge. With a coil giving only $^1/_{16}$-inch sparks in air, he obtained a discharge of about 4½ inches in rarefied air. In 1850 he constructed a very large coil, from which he obtained sparks 8 inches long with a battery of 100 Grove cells.

It is to Ruhmkorff, a skilful mechanician of Paris, that modern electricians are indebted for many of the mechanical improvements in coil construction, and for the addition of the condenser which is used to suppress the spark at the break of the primary circuit, thus performing the same function as the oil on the mercury in Page's interrupter. So many of these coils were constructed by Ruhmkorff that this type of coil is commonly called by his name. One of the largest of these coils was made by him in 1867, the secondary containing 62 miles of wire. This coil could give sparks 16 inches in length. In its construction Ruhmkorff employed a method of winding the secondary so that no two neighboring parts should be at a very different potential. He had before been troubled with internal sparking of the secondary. Instead of winding the wire in layers, he wound it in small flat sections which were placed side by side on the core and connected in series. This method of winding was also employed by E. I. Ritchie, of Boston, who constructed a large coil in 1860 capable of producing sparks of 21 inches with only three bichromate cells. One of the largest of this type of coil ever built was constructed by A. Apps in 1876, and is known as the Spottiswoode coil. The secondary of this coil contained no less than 280 miles of wire in 341,850 turns, and produced sparks 42 inches in length.

The evolution of the alternating current transformer

from the induction coil was but a short step. The first intimation of it came in 1856, when C. F. Varley, of London, took out patents on an induction coil in which the iron wire core was extended and folded back on itself outside the coil, so that the ends overlapped and completed the magnetic circuit. J. B. Fuller, of New York, seems, how-

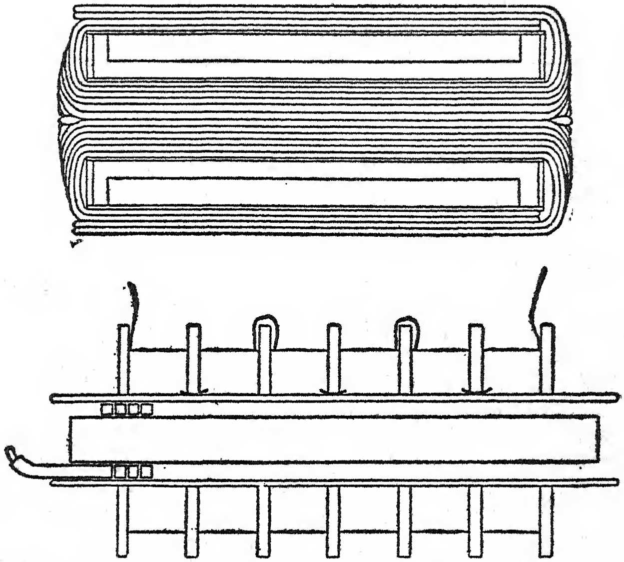


Fig. 20 —VARLEY'S INDUCTION COIL (1856), WITH CLOSED-CIRCUIT DIVIDED IRON CORE.

ever, to have been the first to recognise the value of the transformer as early as 1879, but his death caused the failure of his plans. A number of other inventors attempted to adapt the induction coil to the operation of lights, but they all worked with the idea of connecting the primaries in series, but the loading of each secondary was

found to affect all the others, and the plan was not successful. The last experiment with this series arrangement of primaries was made in 1883 on the Metropolitan Railway in England. A Siemens alternator was put down at the Edgeware Road Station, and a high-pressure alternating current was led through the primary circuits of a series of secondary generators which reduced the pressure. The high-pressure current was transmitted through the primary coils of secondary generators. The length of the primary circuit was 16 miles and the primary coils of the secondary generators were placed in series upon it. Incandescent and arc lamps were worked at these various stations. The impossibility of independent regulation prevented the system from being a success.

The advantages of operating the transformer primaries in parallel from the same mains were first pointed out by Rankin Kennedy in 1883, but were not appreciated and acted upon until they were again brought forward in 1885 by Messrs. Ziperowsky, Deri and Blathy, of Budapest.

In August, 1885, the investigations of these gentlemen were made known in a series of technical papers, and in which the reasons for adopting the parallel mode of arranging induction coils were given fully, as well as descriptions of transformers suitable for this method of working. In the summer of 1885 the Inventions Exhibition was held at South Kensington, and part of the exhibit of the Edison and Swan United Electric Company consisted of a pair of 10 hp. Ziperowsky-Deri transformers working in parallel between a pair of high-pressure leads, and reducing the pressure from 1,000 to 100 volts. The current for these transformers was supplied by a self-exciting alternator, and the primary current was conveyed by a pair of No. 10 B. W. G. insulated copper wires a distance of 800 yards to the place where the transformers were placed. The system was set in operation in London in July, 1885. The transformers were closed magnetic

circuit transformers and the lamps were arranged on the secondary circuit in parallel.

"This was the first occasion," says J. A. Fleming in his 'Alternate Current Transformer,' "on which transformers with their primary circuits arranged in mains were exhibited operating incandescent lamps arranged in parallel on their secondary circuits. This small installation was worked throughout the summer and autumn of 1885 with perfect success. From and after this date the system of parallel working was universally adopted."

Transformers may be divided into four classes, depending on the disposition of the iron core. These are:

(1) Transformers with open or incomplete iron magnetic circuits.

(2) Transformers with closed or complete iron magnetic circuits.

(3) Transformers with an iron core.

(4) Transformers surrounded by an iron shell.

The first type was soon found to produce poor results, altho good for the induction coil, and closed magnetic circuits were used.

There are two common types of transformers, viz., constant potential and constant current. The first are used in such work as incandescent lighting, operating motors, etc., in which the voltage must be held constant. The second are employed to supply arc lamp circuits in which it is necessary to keep the current constant but vary the voltage to suit the number of lamps. Both transformers may operate from the same constant potential mains. In the constant potential transformer both primary and secondary windings remain fixed and the windings are interlaced as much as possible, so that all the magnetic flux created by the primary winding must also pass through the secondary winding. In the constant current transformer, however, this magnetic leakage is utilized to prevent the increase of the secondary current. The fact that the secondary and primary currents in a transformer are

opposite in direction and cause a repulsion between the two coils is here utilized to bring about this result. The secondary coil is movable and its weight is nearly balanced. Any attempt of the current to increase creates a greater repulsive force between the windings, and the secondary moves away from the primary so that less flux from the primary passes through the secondary and the voltage of the latter is reduced. Such transformers are now made which produce an almost constant current in arc lighting circuits. Since 1885 transformers have gradually developed in size, efficiency, regulation of voltage, and ability to withstand high voltage. Transformers of 3,000 kilowatts capacity are now quite common. The voltage regulation is almost one per cent.—*i.e.*, the fall in voltage from no load to full load is only one per cent. Operation is successfully carried on at 110,000 volts.

What were some of the details which had to be developed to produce these large transformers? One of the first things done was to immerse them in oil. The first transformers were exposed to the air, from which the coils absorbed moisture, thus causing them to break down easily. The oil prevented this absorption, and also acted to insulate the windings, as it is very much harder for a spark to pass through oil than through air. In the very high voltage transformers the oil is exposed to a vacuum, and the last trace of moisture in it is extracted.

As the size of the transformer increased, greater difficulty was found in keeping it cool, for altho a large transformer is more efficient than a small one, yet the actual loss increases with the size, but without a corresponding change in bulk. For example, take the case of a 3,000-kilowatt transformer. Altho the loss is only about two per cent., this means an actual loss of 60 kilowatts, or as much heat as would be developed by 1,000 incandescent lamps of 16 candle power. To get rid of this heat, cold water is circulated in pipes through the oil or air is forced over the transformer.

CHAPTER V

THE DEVELOPMENT OF POWER TRANSMISSION

THE location of a convenient spot for the economical generation of electric power usually does not coincide with the center of its consumption, so that the connection of these two points presents a problem which has consumed the energies of many engineers. Among the natural available sources of energy to-day which are most prominent are coal and liquid fuels and the fall of water. Coal and the liquid fuels can, without much expense, be brought to many industrial centers, and the power plant is then erected at these points. In many cases, however, as in the western part of this country, the cost of cartage is prohibitive. On the other hand, water powers are abundant, but are not usually found at points where manufacturing may with profit be carried on.

The power available in such waterfalls, and which has been wasted for centuries, is at last being utilized through the medium of electrical transmission and has become an immense addition to the sources of energy. With the enormous amounts of power now required, the natural resources of fuel are fast becoming exhausted, and America would soon be left without the means of carrying on civilization had not methods of distributing the inexhaustible supply of energy in waterfalls been developed. The importance of the work which has been done and is still being done by those engaged in the design of these power lines is appreciated by few.

Some of the essential parts of such a system of power distribution need consideration. The power-house must be located on a stream which has at all times a sufficient flow to operate the generators at their full capacity. Failing in this, an artificial lake or storage resorvoir may be constructed so that the maximum and minimum flows may be more nearly equalized. In order that the power may be economically transmitted, the voltage of the line must be high, and the higher the better. The loss in the line varies as the square of the voltage, so that with the same line loss the power may be transmitted four times as far by doubling the voltage. It will therefore be seen that the voltage is one of the important factors in determining how far power shall be transmitted. There is a limit to the voltage which a generator may develop on account of its manner of construction, and at present this seems to be about 13,000 volts, altho machines of higher voltage have been built. The next important factor is the transformer, and in the perfecting of this piece of apparatus a great deal of attention has been centered. By its means, the voltage may be raised to almost any degree with a very slight loss in power, the limit being the ability of its insulating materials to resist breakdown. In the last fifteen years the advance in the art of constructing transformers has been such that they may now be built with the same assurance for 100,000 volts as they were then for 3,000 volts. There is, moreover, prospect of their successful operation at 500,000 volts.

Why then are lines not yet operating at 500,000 volts? Now comes the weakest spot of the system, viz., the insulation of the line. The development of insulating materials has not been able to keep pace with that of the means for producing high voltages, altho it has been rapid. Insulators for carrying the lines have increased in size and cost until they have assumed great importance. Wooden poles have been replaced by steel towers, and rights of way have been granted through which the lines

may pass. They are regularly patrolled by men whose business it is to report to the power station immediately any defects observed.

Operation of these lines in actual practice has not been as difficult as laboratory experiments tended to prove. There has been less leakage from the line than was expected and also fewer breakdowns. One of the main difficulties in the operation of these long lines has been due to lightning discharges, but even these are fast being eliminated. New lines are usually troubled with malicious persons who delight in shooting off the insulators, but these have been cured by the severe punishments inflicted. Large birds have sometimes caused arcs to start between the line wires by approaching too close.

Each year sees the limit of successful operating voltage raised. What would have been considered impossible a few years ago is now an accomplished fact. In 1908 the highest operating voltage was 110,000 on a line in Michigan about 100 miles in length; 60,000 is now a standard voltage. To what distances power may be transmitted in the future we may only surmise, but it seems assured that all parts of the world will ultimately be traversed by these power lines. In reviewing the history of the development of power transmission, an idea of its rapidity may be gained by observing the work of the pioneer plants. Altho much of the work was done in Europe, America has accomplished her share and has developed the alternating current system of power distribution to the point where it has finally triumphed over the European direct current system.

During the years from 1880 to 1890 power transmission was effected almost entirely by direct current. Electricity for power and lighting was sent out over the same lines, and the power load usually consisted of a number of small motors. The generators were wound for low voltage so that the lamps could be operated directly from them. Power stations were erected at the centers of distribution.

As the load increased the size of the conductors necessary to give any kind of regulation became very large and the cost of the copper was enormous.

Edison was the first to devise a means of effecting an economy in the weight of copper necessary to transmit a given amount of power, and brought out the Edison 3-wire system, by which it was only necessary to use about three-eighths of the copper employed with the old 2-wire system. This system is still used in both direct and alternating current distributions for lighting. Edison made use of the fact that by doubling the voltage only one-fourth the weight of copper would be necessary, but he added a middle or neutral wire, whose voltage was half-way between the outside wires, so that the voltage between the outside wires was 240, and between either outside and the neutral was 120. The lamps were connected between either outside wire and the neutral, the neutral serving merely to carry the difference in the currents. If, therefore, the number of lamps on each side was the same, the neutral carried no current. If the lamps were properly distributed, it was possible to make the unbalancing current small, so that the neutral wire could be made smaller than the two outside wires. At the power station the 120-volt machines were connected in series and the neutral wire ran from the middle connection.

This was, of course, a great step ahead, as it permitted the transmission of power to greater distances, but the main advantage was the improved regulation—*i.e.*, the increased steadiness of the lights. Even this system, however, was only good for several miles, and therefore did not enable the power station to be removed to a location where fuel and water could be more economically obtained. The system is, however, good for congested districts where the lines are short.

Upon the introduction of the electric railway, the necessity for high voltage was forcibly impressed, and 500-600 volts soon became standard and has remained so un-

til the present time. With this increased voltage it became possible to remove the power station to a point of convenient water and fuel supply. Cars could then be operated fairly well over a radius of 5 or 6 miles without expending too much on the feeder cables.

For several years previous to 1890 Nikola Tesla had experimented with alternating currents with a view to the production of an alternating current motor, and was at last successful. About the same time transformers for raising and lowering the voltage were brought out, and the rotary converter for changing alternating into direct current was exhibited in 1893. This completed the steps in the development of the present alternating current system. The high voltage alternating current generator in the railway power-house gradually displaced the direct-current, and the power became concentrated in one large station, resulting in a more economical production of power. During this evolution the railway lines remained in operation on direct current at 600 volts.

This radically increased the radius of transmission. Sub-stations were erected in various parts of the city, and in these were installed the rotary converters. The power from the central station was all sent out at high voltage as alternating current to transformers, from the low voltage sides of which it entered the rotary converter, which changed it into 600-volt direct current. Each sub-station therefore acted as a supply station, but without the large cost of a generating station. The lines supplied by each sub-station were comparatively short and the voltage of the circuit remained much more nearly constant than before.

One of the largest and most modern examples of this system of distribution is that of the Interboro Rapid Transit Co. of New York City.

Each of the generating units consists of a compound engine and a generator of 3.750 kw. capacity, delivering 25 cycle alternating current at 11,000 volts. The

power is sent out at this voltage directly without the use of raising transformers and delivered to sub-stations along the subway lines. At these stations it is then reduced by means of lowering transformers to such a voltage that when applied to the rotary converter direct current will be delivered at 600 volts, which current operates the railway motors.

This system may be said to have become standard for large cities. Cables for underground use can now be made which are entirely reliable and satisfactory on 11,000 volts. This voltage is, however, as high as engineers will willingly guarantee and dispenses with the use of the large raising transformers necessary with lower voltage generators.

The first transmission of power to a distance in the United States was made in the year 1890, one year before the Frankfort-Lauffen experiment. This station is at the falls of the Willamette River in Oregon, thirteen miles from Portland, where water-power estimated at 225,000 horse-power is obtainable.

In 1893 it had been in successful operation for three years with satisfactory results, both as to the working of the apparatus and the cost of maintenance, the operation of the dynamos being described as admirable and the transformers not having cost a cent for repairs.

The plant, however, to which much of the present knowledge of conditions affecting high-voltage operation is due is that of the Telluride Power Co. in Colorado. This plant operates under particularly severe conditions, and in the overcoming of the obstacles encountered much valuable information was gathered. Here, for the first time, men were systematically trained for operating the plant, each man receiving a general education in all the branches of engineering connected with it. Much of its success was, therefore, due to the knowledge and skill of its operating force. Here that natural enemy of long-distance transmission—lightning—was met and conquered.

"Near Telluride, Colorado," says Atkinson, "is a water-power station from which power is electrically transmitted to the Gold King mill, nearly three miles distant, where it is employed for operating crushers and stamps. It was equipped, when first constructed, with a Westinghouse alternating-current dynamo of 100 hp., operated by

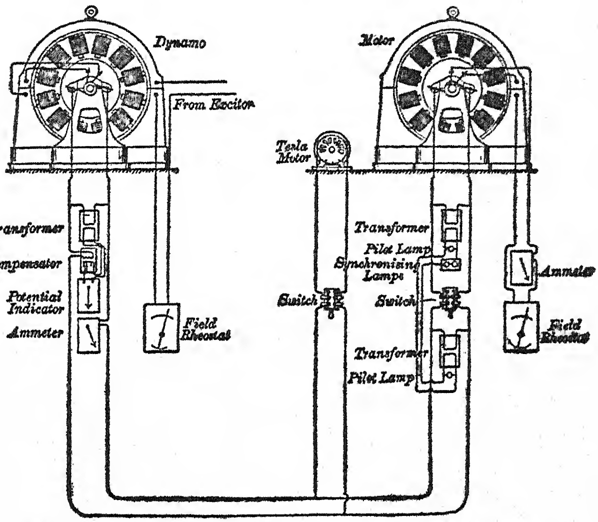


Fig. 21 —Connections of the Telluride Water-power Transmisson.

a Pelton turbine wheel driven by water received through a steel pipe 2 feet in diameter, under a head of 320 feet. The general construction of this dynamo is the same as that of the dynamos employed at the Willamette Falls station, but its field winding is composite, part of the magnets being excited by the armature current of a separate direct-current machine and the others by a current from its own armature, which is made by an apparatus

equivalent to a two-segment commutator, the adjustment being such that the e.m.f. of the current delivered through the mains rises as the current strength increases, compensating for the fall of potential in the line and keeping the e.m.f. at the motor constant at 3,000 volts. The speed is 83 revolutions per minute, producing 10,000 alternations of current.

"The main current flows directly to the motor at the mill without transformation, the only transformers employed being the small ones connected with the indicators on the shunt circuits. The motor is the same in size, horse-power and general construction as the dynamo, and runs in synchronism with it, but is excited by a current from its own armature, obtained from a special winding parallel with the main armature coils, and connected with the field coils by a circuit in which the current is made direct by a commutator. A small Tesla motor of special construction is employed as a starter for the large motor, and is connected with the mains by a parallel circuit, as shown. The armatures of both motors are belted to a countershaft on which the ratio of size between the pulleys is such as to give the armature of the large motor a little higher speed than that of the small one.

"When the circuit of the small motor is closed its armature quickly attains its normal speed, putting the armature of the large one in rotation, at a speed somewhat higher than that of the dynamo, and causing it to generate a self-exciting current at the normal e.m.f. of the circuit. The small motor is then switched off and the speed of the large one gradually decreases till it is approximately equal to that of the dynamo, the relative speed of each machine being indicated by the degree of illumination in incandescent lamps connected in series with the secondary coils of two transformers whose primary coils are connected, respectively, with the circuit of each machine, as shown; the illumination decreasing, from decrease of current, as the speeds of the two ma-

chines approach equality. When the proper relative speed, as thus indicated, is attained, the main circuit of the large motor is closed by its switch and it is connected with the mill machinery by its friction clutch, the small motor having been disconnected by its clutch and brought to rest. The whole operation of starting is accomplished in about two minutes by one man.

If the speed of the motor, on starting, should happen to be a little lower than that of the dynamo it may rise to the proper speed; but if much lower, it will continue to decrease, in which case the switch of the large motor is opened and that of the small one closed, and the speed thus restored. The field current of the motor, as indicated by the ammeter, is regulated, on starting, by a rheostat, and requires no further adjustment for the varying loads. The line runs across a rough country, ascending a mountain at the power station to a height of 2,500 feet, at an angle, in some places, of 45 degrees, and parts of it are practically inaccessible in winter, the snow being sometimes on a level with the tops of the poles. Special protection is required against lightning, to which this region is peculiarly liable, 40 discharges through the lightning arresters having, on one occasion, occurred in 40 minutes. The successful operation of the plant under these unfavorable line conditions, and with a comparatively new type of electric apparatus, since its completion in June, 1891, has inspired such confidence that extensive additions have been made both for power and lighting, which indicates that for the former purpose as well as the latter the employment of the alternating current with long-distance transmission has passed from the experimental to the practical stage." Since the above writing many trials of high voltage have been made at this plant, until it is now operating at 40,000 volts.

The Niagara Falls Power Transmission was one of the earliest, and is still the largest. The first station was built on the American side, and contains ten 5,000-hp.,

two-phase, 25-cycle, 2,200-volt alternating-current generators. Each of these generators is mounted at the top of a long, vertical shaft, at the lower end of which is the turbine. Since the weight of the generator and turbine is very great, too great to be supported by a bearing, the turbine is so constructed that the action of the water tends to balance this weight. The armatures of the generators are stationary and the field magnets revolve outside the armature, being shaped like an umbrella. The best engineering skill in the world was employed in designing the plant, and its success is largely due to that fact. Turbine wheels and generators of that size were practically unknown, and the starting of the plant marked the beginning of a new era in the development of large water-powers.

Since the construction of the first plant another similar one has been built containing eleven units of the same capacity, making the total output of the two plants 105,000 hp. Two other plants also have been constructed on the Canadian side of the river, which deliver part of their power to towns in the United States.

Most of the power from the two American plants is consumed by local manufactories which have sprung up there; 30,000 hp. is sent to the city of Buffalo, about 25 miles away. Since power can be transmitted with 25 per cent. less copper with three-phase than with two-phase current, the two-phase current, generated at 2,200 volts, is changed by transformers to three-phase and the voltage at the same time is raised to 22,000. The distance to which Niagara Falls is transmitting its power is increasing daily, the greatest distance being to Syracuse, 160 miles away, where power is delivered at 60,000 volts.

A typical water-power station, with a transmission line which is said to be, at present, the longest in the world, is that of the Bay Counties Power Co. of California. "This transmission system," says R. W. Hutchinson, in his 'Long Distance Power Transmission,' "is the longest in

existence, and was first put in operation on April 27, 1901. The company supplies power from three plants operated in parallel. Power is transmitted at 40,000 volts to Oakland, a distance of 142 miles from the main generating station, and power is supplied to the Standard Electric Company for transmission to various points along San Francisco Bay, the farthest of which is Stockton, 218 miles distant from the main power plant."

Altho long-distance power transmission by continuous currents is practically unknown in this country, there are many examples of this type in Europe which have operated in competition with alternating current, and which are still being installed. Most of these plants are located in Switzerland and France, and are in satisfactory operation at present. Much of the development in continuous current working has been due to M. Thury, a French engineer, and the originator of the system which bears his name. In this system a number of series-wound generators are connected in series, so that their voltages add together. It is evident, therefore, that any voltage may be generated by connecting together a sufficient number of such machines, and 60,000 volts have in this manner been obtained. Direct-current generators of this type can be built which will operate satisfactorily as high as 4,000 volts. In obtaining the 60,000 volts above mentioned sixteen of these generators are connected in series. Each machine is substantially insulated, both from the floor and from its driving turbine. The Thury system is known as a "constant-current" system, because the current is held constant no matter what the load may be; but the voltage is varied, so that at light loads the voltage is low, and reaches its maximum only at times of full load.

The line is very simply constructed, consisting of two wires, and in case of accident to one wire the earth may be used as a return. The line, therefore, presents a much simpler construction than that for an alternating-current

system requiring three wires. At the receiving end the electrical power is converted into mechanical power through a number of series motors connected in series across the line. A centrifugal governor attached to each motor holds its speed constant by varying its field strength. For this purpose a portion of the current (which is always the same) is shunted from the field through a resistance.

What are the advantages and disadvantages of this system? The chief advantage claimed for it by its advocates is the simplicity of its line construction. With direct current the insulation of the line is only subjected to the effective voltage of the line, while in an alternating-current transmission the voltage which the insulators must stand is at least 1.4 times the effective line voltage; and, in addition, surges of waves of voltage are liable to occur which may double this value. It will therefore be apparent that the direct-current line has a decided advantage. Another advantage claimed for it is its ability to operate during lightning discharges, since more effective arrangements may be made to prevent the lightning from entering the stations.

Coming to the stations, however, the direct-current system has serious drawbacks. It has not been found practicable as yet to build the generators larger than 400 kw. output. To equal one of the Niagara Falls power stations in output would, therefore, take 125 such generators. Advocates of the alternating-current system have always considered these stations too complicated for satisfactory operation. It must be admitted, however, that M. Thury, through persistent work, has simplified the station to such an extent as fully to meet this objection.

On the whole, alternating-current transmissions seem to be more satisfactory than the direct current, and this advantage will increase as alternating-current motors reach the perfection attained by direct-current machines and line insulation becomes so perfected as easily to withstand the voltages imposed upon it.

Regarding recent developments in high-voltage transmission and its future limits, the 'Engineering Record,' August 15, 1908, says: "It is just now worthy of special comment that the record for high voltage has again been raised, this time to the soaring figure of 110,000 volts. For once the palm for sensational engineering has left the Pacific coast, to repose, for a while at least, in the custody of the Central States. This latest step forward must really be regarded as epoch-making, since it carries the art of power transmission from the region of the tried and standard into the unknown country beyond; and the best of it is that the incursion has apparently been a victory. It is a new proof that all things come to him who dares.

"At last the next great step has been taken, thanks to the enterprise of the insulator maker, and especially to the construction of the suspension type of insulator, which makes relatively easy pressures before difficult. The pin insulator, when constructed of dimensions adequate for very high voltage, became unwieldy and mechanically troublesome; not so the suspension insulator, which actually leads to improvements in line construction. It will probably be found, too, as is often the case, that the precautions now considered necessary in going to very high voltages will prove to be more than adequate in the light of practical experience. It is a fact that in Continental practice surprisingly small and simple insulators have been found entirely successful for pressures considerably higher than would be attempted with the same material here. American engineers attach great importance to preserving a high line insulation, as they should, but they went through a period in which the size of insulator was all out of proportion to their quality and design. Now, practice is settling into sounder lines and will go on to better and better results. The fact is that at every stage of progress toward high voltage advance has proved to be easier than seemed at first possible. Difficulties that seemed insuperable have been, time and

again, overcome with comparative ease, so that now one is not beside the mark in counting upon a very general advance in the near future. Of course, the plants in which 100,000 volts or more is a figure commercially necessary are relatively few. As time goes on, however, and the more remote powers are utilized, high voltage will become more and more necessary, and will be more generally employed.

"As to the limits which may be reached one would be unwise to prophesy. At 100,000, or about there, a condition is reached where, save for large powers and long wires, further increase would lead to wires too small to be desirable mechanically. In addition, it is undesirable, for electrical reasons, to use anything much below a quarter inch in diameter at very high pressure, so that there is a natural limitation to the number of very high voltage plants. Yet, for the really big work of the future, success depends on just such bold achievements as the one here considered. The next step will probably be in the direction of a very long line at extreme voltage. Here, again, is a debatable ground, owing to line difficulties. No one has yet operated a line of such length as to be a material fraction of the natural wave-length corresponding to the frequency. There is a possibility of a new class of troubles arising under such circumstances, and new devices may be required to meet it. It is on such very long lines that the use of high-tension continuous current has found some advocates. Severe requirements as to the use of cables is a possible source of future trouble, but here also the manufacturer may be counted on to push ahead; 20,000-volt cable is in use in England to the extent of several hundred miles, and 40,000-volt cable has been successfully worked, so that if the time should demand underground lines at 100,000 volts or more it is safe to say that they would be forthcoming."

CHAPTER VI

THE HISTORY OF ELECTRIC LIGHTING

The history of electric lighting begins soon after the discovery of electric currents. In 1800 Sir Humphry Davy, while experimenting with the effects of currents, obtained bright sparks between two charcoal points upon breaking the contact between them. The number of cells with which he worked was, however, insufficient to produce a continuous light. After a few years he increased the number of cells in his battery until it was composed of 2,000 elements. With this powerful source of current he was able to obtain a continuous discharge between carbon points which sustained itself across a gap of 7 inches and emitted a dazzling light. This light was exhibited in 1813 at the Royal Institution. Davy found that the conducting power of the charcoal points was improved by extinguishing the charcoal under mercury. The consumption of these points was very rapid. The name "voltaic arc" came from this experiment of Davy's, from the fact that the stream of vapor formed itself into a bow, the charcoal points being horizontal.

Owing to the high cost of producing the electric current no one seems to have cared either to develop a lamp or to ascertain the properties of the arc itself until 1844, when Foucault constructed a lamp using carbons from the retorts of gas works, which were much harder and more compact than Davy's charcoal points and less easily consumed.

Thomas Wright, of London, devised the first apparatus (1845) in which the adjustment of the carbons is brought about automatically. W. C. Staite used the electric current for the regulation of the carbons in 1848. In 1858 Foucault devised a lamp in which the carbons were made to approach automatically by means of a clockwork feed, the clockwork being controlled by an electromagnet. As the current diminished in strength, due to the increase in the length of the arc as the carbons burned away, a magnet in series with the arc weakened and released the escapement of the clockwork, thus moving the carbons together. In this lamp both carbons moved, and were so regulated in their motions as to maintain the arc in a fixed position. In later lamps, used for general illumination, this was not considered necessary, and the regulating mechanism was considerably simplified. The lamps were known as "focussing" or "self-centering" lamps, and are still necessary in some cases, such as stereopticon work.

Before proceeding with the history some of the properties of the arc may be examined. If it is attempted to produce an arc by means of a few cells of battery the attempt will be unsuccessful. It is necessary that a difference of potential of about 40 volts should exist between the carbons before any stream of vapor will be formed. The longer the arc produced the higher is the voltage necessary to maintain it. In the ordinary carbon lamp practically no light comes from the arc itself; it is all emitted from the white-hot carbon points. If the source of current is direct or continuous, most of the light is radiated from the positive carbon, or that by which the current enters, and this carbon is consumed about twice as rapidly as the other. From this fact it will be seen that in such lamps as Foucault's it was necessary to arrange the mechanism so that the positive carbon should move at about twice the rate of the negative. Another peculiarity is the manner in which the carbon points burn away.

When the combustion takes place in the air the positive carbon has a depression or "crater" formed in it, and upon the negative is produced a nib. This seems to be due entirely to the fact that combustion takes place in air, as the phenomenon disappears when the arc is enclosed, and both carbons become blunt. This seemingly slight difference was, however, a factor of considerable consequence, as the greater part of the light is emitted from the intensely hot crater of the positive carbon, so that in the open arc much of the light is cut off from the horizontal direction by the rim of the crater, which is removed by enclosing the arc. The temperature of the arc is the greatest of all earthly temperatures, nearly all substances volatilizing almost instantly.

Arc-lamp development was stimulated by the construction of the magneto-electric machine, which greatly decreased the cost of power. The introduction of the dynamo, however, completely solved the problem of power, and the field was immediately opened for the electric light.

One of the first successful lights was the electric candle of Paul Jablochkoff, invented in 1876. This is probably the simplest of all electric lamps. As shown in Fig. 22, it consists of two carbon rods placed parallel, and separated from each other by plaster of paris, the rods having brass tubes at their lower ends which make contact with springs set in the holding device. To start the candle a thin plate of graphite was laid across the tip, this being heated by the passage of the current sufficiently to start the arc. Difficulty was, of course, encountered in operating these lamps on direct current on account of the unequal rates of burning of the positive and negative carbons. It was attempted to overcome this by making the positive twice as thick as the negative carbon, but the ratio not being exact, and liable to variation, caused the failure of this method. They were therefore operated on alternating current, and over 4,000 were in use in Paris alone. The lamps, however, were not satisfactory, and

inventors gradually reverted to the lamp with the adjusting mechanism.

As soon as arc lamps had to be operated over a considerable territory it was seen that the mode of connection, known as "series," wherein a single wire is used to connect the lamps together, was preferable to the "parallel"

Fig. 22 —THE JABLOCHKOFF CANDLE.

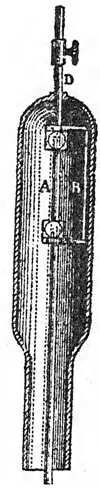


Fig. 23 —THE STARR-KING INCANDESCENT PLATINUM LAMP, 1845.

system, which required two wires, both in economy of wire and in saving of power. This required a special arrangement of the lamp mechanism. On the series system the same current passes through each lamp, and since it requires about 50 volts to operate a lamp the generator must develop as many times 50 volts as there are lamps. This necessitated the construction of a generator which should develop a high voltage, as there were often as

many as 125 lamps on one line, requiring 125 × 50, or 6,250 volts. Such a suitable generator was devised by Mr. Charles Brush, and is known as the Brush arc-lighting dynamo.

Returning to the mechanism of the lamps suitable for

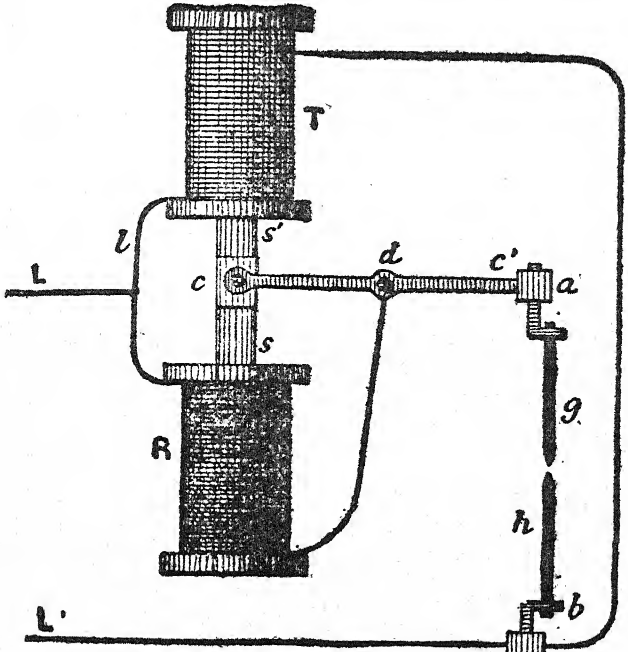


Fig. 24 —Diagram of Siemens' Differential Lamp.

such a circuit, one of the first of these was constructed by Hefner Alteneck, and is known as the Siemens differential lamp. This type of regulator is still in use, altho, of course, modified and improved. Fig. 24 illustrates the method of regulating. The lower solenoid R is known as

the "series" coil, and carries the same current that passes through the arc. The upper solenoid T has many turns of fine wire and is connected across the arc. The two coils act upon the same core in opposite directions, hence the name "differential." If the carbons approach too closely the current in the series coil increases and pulls them apart, but as the length of the arc is increased thereby the voltage across it grows greater and the shunt coil T receives more current. This prevents the series coil from producing too great a motion, and the carbons are held by the balancing action of the two coils. The upper carbon alone is fed down by the action of gravity, the lower carbon being fixed. This style of lamp was also developed by Brush in America, and many thousands have been used. The combination of the Brush high-voltage generator and the differential-series lamp was quite satisfactory as a means of lighting, and many of these arrangements are in use at the present time, altho they are fast being replaced by more modern systems.

With the open arc lamp of the Brush type the replacement of the carbons was required daily, and became quite an item in the total expense of operation. About 15 years ago arcs enclosed by a thin glass were introduced which required trimming only once in ten or fifteen days. At first it was thought that the enclosing glass would cut off so much of the light as to seriously impair the efficiency of the lamp. The fact previously mentioned concerning the flattening of the carbon tips and a consequent better distribution of the light here came to the aid of the enclosed lamp, so that altho there was some loss of light due to the glass, the improved distribution overbalanced that effect. A grave fault, however, was the deposition of the silicious impurities of the carbons on the enclosing glass, with a consequent diminution in the light. Efforts were accordingly directed toward the improvement of the carbons, and altho it has not been found

possible to produce carbons free from such material, that fault is not at the present time serious.

Altho the series system of operation is the only practicable one over long distances, it is often required to operate arc and incandescent lamps on the same circuit, as in buildings, etc. For such work the differential mechanism of the series system is not suitable. In that system the lamps act to steady one another, for with so many in circuit the fluctuations of one lamp do not appreciably affect the current in the circuit. The operation of a single lamp requires, therefore, something to replace the steadying action of the other arcs, and this is accomplished by means of a dead resistance. Some energy is, of course, wasted in this resistance (about 25 per cent.), but the operation is very satisfactory.

The ordinary carbon arc lamp, altho one of our most efficient sources of light, is still far from the ideal. Of the total energy radiated from it only about 10 per cent. has the proper frequency of vibration to affect the eye as light. The ideal light would emit rays all of which would affect the eye. One means of effecting this increase is to raise the temperature of the heated body; another, to employ a different material, since all materials do not emit equal light at the same temperature. Attempts to utilize the latter principle resulted in the production of "luminous" and "flaming" arcs. Some of the most prominent workers on this subject are Bremer, Auer, Nernst, Blondel, Whitney and Steinmetz.

The luminous arc is composed of two electrodes which supply a stream of light-giving vapor. One of the most prominent examples of this type is that developed by Mr. Steinmetz, and known as the magnetic arc. The positive electrode is a rod of copper, the negative a rod of magnetite, or iron ore. The light given off is an intense greenish white, the efficiency being several times that of the ordinary arc. They have recently been established on a commercially operative basis, altho still unsatisfac-

tory in some respects. They can operate only on direct current, which usually involves the rectification of the alternating current, now almost universally generated.

The flaming arc is almost invariably produced by utilizing the intense heat of the carbon arc to render incandescent various refractory materials. For this purpose either one or both of the carbons are impregnated with metallic salts having great light-giving power, as calcium, titanium, strontium, etc. The most efficient of these are the salts of calcium, which emit dazzling yellow rays. For some purposes—as interior lighting—these rays are objectionable on account of the distortion of color which they produce, and the salts of titanium are preferred, as these emit a beautiful white light, altho of less intensity. The lamps may be operated on either direct or alternating current. The objectionable features of these lamps are the increased cost of the carbons and their short life. For that reason they have not yet come into general use for street lighting. In respect of life the magnetic arc has the advantage, its life being about the same as the enclosed carbon arc—150 hours.

Developments in arc lighting have followed one another with such rapidity during the last seven or eight years, and are still progressing so swiftly, that one hardly knows where they will stop. The fine organizations of engineering and scientific skill under the control of large electrical enterprises have made possible these rapid developments of the last few years.

"Admirable as is the system of electric-arc lighting for use in streets and open spaces, and in workshops or large halls," says Henry Morton in his 'Electricity in Lighting,' "it is entirely unfit to take the place of the numerous lights of moderate intensity employed for general domestic illumination. For this purpose it was at a very early period perceived that the incandescence, or heating to luminosity, of a continuous conductor by an electric current was the most promising method. It was also at a

very early period perceived that the conductor to be used for this purpose must be one which would admit of being raised to a very high temperature without being melted or otherwise destroyed. The first material which was thought of in this connection was platinum, or one of its allied metals, such as iridium, which have the highest melting points among such bodies, and are, besides, entirely unacted upon by the air at all temperatures.

"In 1848 W. E. Staite took out a patent for making electric lamps of iridium, or iridium alloys, shaped into an arch or horseshoe form. One of the most serious difficulties, however, even with these materials, was that to secure from them an efficient light it was necessary to bring them so near to their fusing points that a very minute increase in the current would carry the temperature beyond this and destroy the lamp by fusing the conductor.

"An escape from the difficulty was offered by the use of hard carbon, such as that employed for the electrodes of arc lamps; but here the compensating drawback was encountered that this substance, when highly heated, was attacked by the oxygen of the air, or, in other words, burned. To meet this plans were devised for the replacement of the consumed carbon in a non-active gas or in a vacuum. Thus, in 1845, a patent was taken out in England by Augustus King, acting as agent for an American inventor named J. W. Starr, for an incandescent lamp, the important parts of which are represented in Fig. 23. Here a platinum wire is sealed through the top of a small glass chamber constituting the upper end of a barometer tube. This platinum wire carries at its power end a clamp, which grasps a thin plate or rod of carbon, and also a non-conducting vertical rod or support, which helps to sustain another clamp, which grasps the lower end of the carbon strip and connects it by a wire with the mercury in the barometer tube below. By passing a current through the platinum wire, and thence through the upper clamp,

carbon strip, lower clamp, wire and mercury, the carbon strip could be made incandescent, and was to a certain extent protected by the surrounding vacuum. Tho this lamp produced a brilliant light, it proved in various respects unsatisfactory, and was abandoned after numerous trials. Other inventors, as, for example, Konn, of St. Petersburg, continued to work with rods or pencils of hard carbon and achieved a limited success, but the irregularity and brittleness of the material seem to have been an insuperable objection and drawback, and the problem of commercial electric lighting by incandescent conductors yet remained without a solution.

"This was the state of affairs even up to the fall of 1878, when, as is claimed, William E. Sawyer, in combination with Albon Man, after many preliminary experiments, produced their first successful incandescent lamp with an arch-shaped conductor made of carbonized paper. In their application for a patent, filed January 8, 1889, these inventors use the following remarkable language in their fourth claim: 'An incandescing arc of carbonized fibrous or textile material.' This indicates that they realized the importance of what seem to be the common features of the present electric incandescent lamps, namely, the arc or arch or bow or loop form, and the carbonized fibrous or textile material. They also specially refer to carbon incandescent conductors made from paper.

"After a long and hotly contested interference, the United States Patent Office has granted them a patent in which these points are broadly stated. The lamp brought out by Messrs. Sawyer and Man, soon after their application for a patent, and described and shown in that application, was a rather large and complicated structure, and had no improvement and simplification of this structure been made the present immense development in electric lighting would no doubt have been unattained. It is to T. A. Edison, without doubt, that we owe many of the simplifications and modifications which, by cheapening the

lamp and diminishing its weight, have extended its range of use and its usefulness to a remarkable degree. On his return in the fall of 1878 from the far West, where he had gone in company with Dr. and Mrs. Henry Draper, Dr. George P. Barker and the present writer, to observe the total solar eclipse of that year, Mr. Edison visited the shops and laboratory of William Wallace, at Ansonia, Conn., where many experiments with electric-arc lights and dynamo-machines were in progress, and while study-

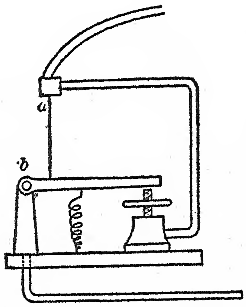


Fig. 25 —EDISON'S FIRST INCANDESCENT PLATINUM LAMP.

ing these was impressed with the desirability of producing an incandescent electric lamp. Like so many before him, he first turned to platinum and platinum alloys, and devised a form of lamp admirable for its simplicity, but, unfortunately, open to a fatal objection. This first lamp of Edison's is shown in Fig. 25, in which a b is the incandescent platinum wire.

"The announcement of a new system of electric lighting, made by Mr. Edison and his friends on the foundation of this device, attracted universal attention, and even caused a serious fall in the value of 'gas stocks' in this country and abroad. It is, indeed, amusing now to look back upon the extravagant assertions and predictions made at that time and widely circulated when we realize how

more than frail was their foundation. In fact, Mr. Edison very soon found out that this simple device was entirely insufficient for the purpose proposed, because the heated platinum wire gradually stretched by its own weight, and thus was constantly getting out of adjustment, and finally would become attenuated and break.

"It also happened that, though the secret of this great invention was carefully guarded, some inkling of it escaped, and this enabled those who were familiar with such subjects to perceive the close similarity between this Edison lamp and a similar device constructed and used by Dr. J. W. Draper prior to 1847, and described and figured in articles published by him during that year in the American Journal of Science and Arts, The London, Edinboro and Dublin Philosophical Magazine, and Harper's New Monthly Magazine. This apparatus was used by Dr. Draper as a source of light or lamp with which he determined the relations between temperature and luminosity. At the conclusion of his article Dr. Draper says: 'An ingenious artist would have very little difficulty, by taking advantage of the movements of the lever, in making a self-acting apparatus in which the platinum should be maintained at a uniform temperature notwithstanding any change taking place in the voltaic current.'

"It also appeared that precisely the same idea had occurred to another inventor, Hiram S. Maxim, who has recently developed such a marvelous improvement in magazine or repeating guns, and who, on December 22, 1879, filed an application for a patent which, after an interference litigation with Edison, was finally issued to Maxim on September 20, 1881, for the form of electric lamp shown in Fig. 26. It has also been shown that in 1858 M. G. Farmer, one of the veteran electricians of America, to whose work in connection with the dynamo-electric machine allusion has been made before, lighted a room in his house at Salem, Mass., for several months with platinum lamps of similar structure controlled by automatic regula-

tors. During 1878 and 1879, however, Mr. Edison was most diligently at work, and perceiving the imperfections of his first ideas, sought in every way to overcome them It thus came to pass that by December 21, 1879, at which date he made his first revelation to the public, in the pages of the New York Herald, he had perfected a platinum lamp which is shown in outline in Fig. 27, as well as some other forms substantially like it.

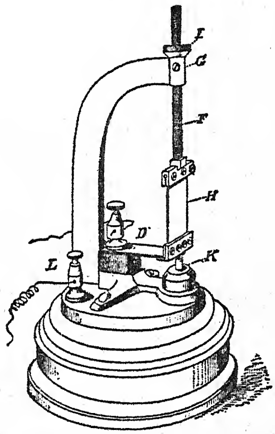
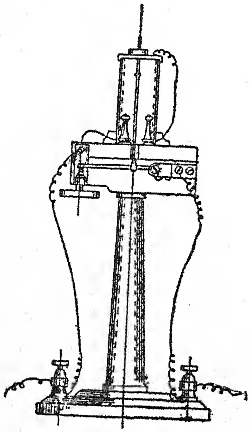


Fig. 26 —MAXIM'S INCANDESCENT PLATINUM LAMP.

"But these platinum conductor lamps were not the only outcome of Mr. Edison's work between the fall of 1878 and December, 1879. As this Herald article also related, Mr. Edison, like many before him, having experienced the insuperable difficulties present in metallic conductors, had turned his attention to carbon in various forms; and, like Sawyer and Man, had found fibrous textile materials, when carbonized, to be most convenient, and paper especially to be, in the first instance, the most available substance. Like Sawyer and Man, he had also found the

arch, or horseshoe form, to be the most desirable. Tho working with the same materials and form, Edison produced a structure very different in appearance from that of Sawyer and Man, as will be seen by reference to Fig. 28, which represents one of Edison's paper carbon lamps, which was the first one whose electric properties were accurately measured, these measurements having been made at the Stevens Institute of Technology, early in 1880, by



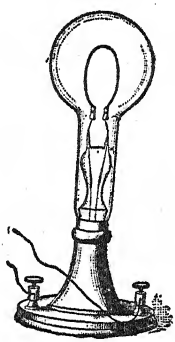


Fig. 27 —EDISON'S PLATINUM LAMP ON COLUMN SUPPORT, 1879.
Fig. 28 —EDISON'S PAPER CARBON LAMP.

the present writer, acting in his capacity as Chairman of the Committee on Scientific Tests of the United States Lighthouse Board, that body desiring information as to this new light, and deputing the work of investigation to this committee.

"In this lamp the carbon conductor is supported on platinum wires and held in minute platinum clamps at the ends of these wires, which are sealed through the walls of the pear-shaped enclosing tube in the manner which has been

familiar for twenty years in the construction of the beautiful toys known as 'Geissler tubes.' The interior of this glass vessel had likewise been exhausted and hermetically sealed in the manner usual with many Geissler tubes and with the radiometers of Dr. William Crookes."

Since its invention the Edison lamp has maintained a practical monopoly, and it is only within the last few years that other competitors have loomed up which threaten its supremacy. They still have difficulties to surmount, however, which have already been overcome in the carbon-filament lamp.

Edison's first filaments were made of carbonized thread or paper. It is obvious that such filaments could not be made with any great uniformity. A great many experiments were made and are still being made to determine the best method of making them. They are all, however, made by what is called the "squirting" process, of which an outline follows.

Pure cellulose, as cotton-wool or blotting-paper, is dissolved in a concentrated solution of zinc chloride until a jelly-like mass is obtained. Great care is required to obtain pure materials, and the various processes must be closely watched. This mass is filtered by forcing it through a suitable filter such as glass-wool, fine wire-gauze, or flannel. It is then heated under a vacuum to free the viscous material from air carried into it by the cotton-wool or cellulose. It is then squirted under fairly high pressure through a fine orifice, which just dips below the surface of acidified alcohol contained in a tall glass jar. The alcohol hardens the cellulose, which forms a fine thread of a diameter depending on the size of the orifice. By revolving the jar, the thread is coiled in it. When hard, it is removed and washed and wound on drums to dry. When dry it has the appearance of catgut. It is then given the desired shape by being wound on molds and baked. Bundles of filaments are then packed in carbon powder in

plumbago crucibles which are raised to as high a temperature as possible.

The carbonized filaments are gauged for diameter and the legs cut to the required length, after which they are ready for mounting on to the leading-in wires. There are two methods for doing this. In one, the ends are laid against the leading-in wires and a drop of paste composed of graphite mixed with a binding material is applied, the paste being afterward dried in an oven; in the other, by heating the joint red-hot in an atmosphere of benzene, the benzene having decomposed and carbon deposited.

The filament is then "flashed" in order to make it more uniform and increase its life. Flashing is accomplished by placing the filament under a bell-jar filled with hydrocarbon vapor, and raising it to incandescence by the passage of a current, whereupon the vapor is decomposed and a firm compact coating of carbon is deposited upon it. The greatest deposit takes place where the filament is thinnest, as the current causes it to heat most in that part. Flashing, therefore, smoothes out the irregularities of the filament.

The filaments are next sealed into bulbs and the bulb exhausted. In the early days, Sprengel mercury pumps were used, but these were very slow, altho very perfect. Nowadays, a little phosphorus dissolved in alcohol is introduced into the stem, which is then connected to a mechanical air-pump having oil-sealed valves and exhausted as far as possible. The stem is then sealed a short distance below the bulb and the phosphorus vaporized by a little heat into the bulb, where it combines with the remaining oxygen and completes the exhaustion. The lamp is then properly sealed off.

The first patents covering the principle of the Nernst lamp were taken out by Professor W. Nernst in 1897 and 1898. In its first form it was very crude, serving mainly to show the fact that the filaments could be produced and that their efficiency was about twice that of the ordinary

carbon filament. This was the first incandescent lamp to threaten the life of the Edison carbon filament lamp. Much was promised for it at first, and its development was vigorously taken up in this country, England and Germany. Altho the lamps are still manufactured, very few are in use, and it is probable that the manufacture of them will soon cease entirely. The recent introduction of the tungsten lamp has made its existence unnecessary, as it is surpassed by the tungsten lamp in efficiency, life and first cost. It contains, however, a very interesting principle, viz., the employment of an electrolytic conductor as the incandescent body. This conductor or glower, as it is called, is practically non-conducting at ordinary temperatures and requires to be heated before it will allow the passage of current through it. This fact is probably the principal cause of its failure commercially, as the heating apparatus is quite complicated, of uncertain life, and the time consumed in lighting (sometimes half a minute) is in many cases objectionable. This is the only electric lamp that can be started with a match and blown out.

The glower of the American form of Nernst lamp is said to consist of the oxides of several rare metals, such as yttrium, ytterbium, thorium, etc., altho the true composition is known only to a few. The glowers are in the form of a short, thick filament, cemented to flexible platinum terminals by which it is suspended below and close to heating coils, consisting of porcelain tubes in which are imbedded resistance wires. These resistance coils are, of course, necessary to bring the glower up to the temperature at which it begins to conduct. The heating resistance is connected in shunt with the glower, which has in its immediate circuit an electro-magnetic switch for opening the heater circuit. When the glower becomes sufficiently heated to conduct, the current in this portion of the circuit operates the electro-magnetic switch and automatically cuts out the heating coils.

As the glower conducts electrolytically rather than as a

solid, up to the present it has given a much shorter life when used on direct or low frequency alternating current circuits than with higher frequencies. Altho up to the present time these lamps cannot be called a commercial success, recent developments and improvements in constructional details have made the efficiency of the lamp equal to that of the tungsten. If a method of producing a lamp free from the complicated starting apparatus which now prevails is discovered, these lamps may be heard from again.

These lamps have followed one another in such rapid succession that some of them, altho full of promise, have never been long in the commercial field, having been succeeded by others still better. Incandescent electric lamps with metallic filaments are older than carbon-filament lamps. As long ago as 1840 lamps were constructed with filaments of platinum, and for thirty years after that date various attempts were made to construct a practical lamp, using either platinum or iridium wires for the filaments, the only two metals at all suitable which were obtainable at the time. None of these attempts met with any commercial success, and the use of metals was finally abandoned in favor of carbon by the experimenters who developed the carbon-filament lamp in 1878-1880.

The success attained with carbon caused all consideration of metallic filaments to be put on one side for nearly twenty years. The introduction of the Nernst lamp appears to have then stimulated research afresh, and many inventors turned their attention to the metals, to find the field greatly widened by the chemical progress which had been made in the meantime. Instead of only two possible metals to work with, there were now numbers known with sufficiently high melting points to suggest great possibilities. After much painstaking effort and laborious work, carried out by inventors who deserve the highest possible praise for both their ingenuity and their perseverance, three commercial metallic-filament lamps have been evolv-

ed which have entirely altered the outlook for the future of the electric lighting industry.

"It is possible," suggests Maurice Solomon in his "Electric Lamps,' "that these may prove to be only the forerunners of further improvements; rumors of fresh developments are of almost weekly occurrence, and it is difficult to say at the moment what is likely to be the course of events during the next few years. Up to the present none of the rumored improvements have given any evidence of being advanced beyond the laboratory stage, and many do not appear even to have reached that stage, tho some have been proved commercial, namely, the osmium, tantalum, and tungsten (Wolfram or Osram) lamps. The osmium lamp is the invention of Dr. Auer von Welsbach, and the earliest patents relating to it were taken out in 1898. The earlier reports in reference to the osmium lamps appeared in the technical press in 1901, but the lamp does not appear to have been manufactured commercially until 1903, and it was not until 1905 that it was introduced into this country by the General Electric Company.

"The method of manufacture may be gleaned from the patents and from a paper read by Dr. Fritz Blau before the Elektrotechnisher Verein in 1905. The process first tried was that of flashing platinum wire in an atmosphere of osmium tetroxide (which is volatile). By subsequently incandescing the alloy in vacuo the platinum can be evaporated off, but it was not found possible to produce sufficiently thin filaments in this way. Finally the method adopted was that of pressing finely-divided osmium, mixed with an organic binding agent, through small diamond or sapphire dies. The thread thus formed is carbonized, and the carbon is then driven off by incasing the filament in an atmosphere of steam and hydrogen.

"The filaments have to be raised to a very high temperature in order to "sinter" together the osmium particles into a practically homogeneous filament. Sintering may be described as a sort of modified welding process; the metal

does not fuse, but the particles raised almost to their melting point bake together and bind very firmly; as a matter of fact exactly the same phenomenon occurs with carbon filaments, which after the first stages of baking are highly porous, but become dense and homogeneous on further raising their temperature. The osmium filaments are mounted in bulbs in the same way as carbon filaments, the mount being made by fixing together by means of an arc the end of the osmium filament and the leading-in wire. The osmium lamp has been described on account of its interesting position as the first of the new metallic filament lamps. The lamp must be regarded at present as already obsolete, having given place to the tungsten lamp, the filament of which is similar in character to the osmium filament, but in many respects superior.

"The earliest patents in relation to the tantalun lamp were taken out by Messrs. Siemens and Halske in 1901 and 1902, but the lamp was not introduced commercially until 1905. During 1906 and 1907 the lamp has steadily grown in popularity, and the number now in use is very large. The tantalum lamp can certainly claim to be the first metallic filament lamp which proved to the full its suitability by the development of its formidable rival, the tungsten lamp, and it will continue to be remembered as the first lamp to afford solid ground for the hope of a marked advance in electric incandescent lighting. The filament of the tantalum lamp is made from pure drawn tantalum wire, and one of the chief difficulties in its manufacture is the preparation of the pure tantalum in a form suitable for drawing.

"Tantalum metal is obtained in a powdery form by reducing potassium-tantalo-fluoride; the powder is then fused electrically in vacuo, the process serving not only to produce the metal in a coherent form but also to drive off the occluded gases. The fused ingot is drawn into wire, the precise method by which this is done not being published, but the process must be one of considerable dif-

ficulty in view of the extreme hardness of the metal, which is, however, ductile and the tantalum wires are quite flexible. The metal oxidizes readily, and when heated burns away completely to oxide; the filament must therefore be mounted in an exhausted bulb, and the difficulty of disposing of the necessary length in the bulb has been overcome in an ingenious manner (rendered possible by the flexibility of the wire) by winding it on a frame as shown in Fig. 29. In this figure, for the sake of greater clearness, only

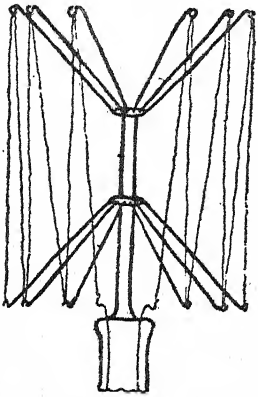


Fig. 29 —METHOD OF SUSPENDING TANTALUM FILAMENT.

Fig. 30 —METHOD OF SUPPORTING TUNGSTEN FILAMENT.

the front half of the frame and filament is shown. This frame is mounted in a bulb in the usual manner. The other details of the lamp call for no special mention. Probably, apart from the difficulty in making the original tantalum wire, the lamp is one of the easiest of the metallic-filament lamps to manufacture, which leads to the hope that it may be greatly reduced in price when competition renders this necessary.

"The earliest patents relating to the production of fila-

ments of tungsten appeared in 1904. The most important are those taken out by Just and Hanaman, Kuzel, and Welsbach. In 1905 and 1906 many other patentees covered processes for manufacturing these filaments, but it must be remembered that by this time the possibilities of the metallic-filament lamp were becoming well recognised and many who patented methods and processes probably did so only in the hope that their ideas might some day prove fruitful. The credit for the development of a commercial lamp rests with the inventors already named, and lamps are now manufactured by all three of the processes which they devised.

"It is too early to say which of these is likely to survive; possibly some modification combining the advantages of all will prove ultimately the most efficient and reliable manufacturing process. The tungsten lamp appears to have a brilliant future before it. While in its present form it lacks some of the advantages of the tantalum lamp, the fact that the consumption of power per candle is only about half that with tantalum will cover a great many defects. Unless a new metal filament is brought forward with an efficiency markedly superior, it is difficult to see what competitor now in the field can stand long against the tungsten filament."

The commercial development of the tungsten lamp has been conducted with marvelous rapidity. Everywhere they are rapidly displacing the carbon filament lamps. Their fragility, however, restricts their use to places where they are not subjected to mechanical vibration, altho by ingenious methods of mounting this defect is fast being overcome.

The idea of producing light from incandescent vapors has always been an attractive one. Theoretically it is possible to obtain a far more efficient light from these vapors than from incandescent solids, because the emanations are more nearly of the same frequency than those from solids. Discharges in vacuum tubes have been tried for many

years and there was developed a form of tubes, known as Geissler tubes, in which the most beautiful effects were produced by discharges through rarefied gases, but their brightness was never sufficient for practical lighting.

About ten years ago Peter Cooper Hewitt, making use of the fact that a column of mercury vapor is a good conductor, succeeded in constructing a mercury vapor lamp of great power and efficiency. This lamp consists of a long glass tube, having two electrodes, the negative of which is mercury. The arc is formed between these electrodes and completely fills the tube. This is, therefore, a true arc lamp. The lamp must be burned in an inclined position, the mercury being in constant circulation. It is vaporized at the lower end, condensed at the upper, and runs back to the lower again. One feature, which for general lighting is objectionable, is the color distortion produced by this light. Since there are no red rays in it, red bodies appear black, and all objects have a greenish-blue appearance. For purposes of photography, for drafting-rooms, etc., it is, however, admirable, being rich in the upper rays of the spectrum.

Following out the idea of producing light from discharges in a vacuum, MacFarlane Moore has succeeded in producing a lamp which is extremely ingenious. The chief advantage claimed is the improved distribution of the light, the light being nowhere intense. The tubes may be made an hundred or two feet long and may be fitted to suit the shape of the room. The discharge is effected by means of a high-voltage transformer. The tubes give off a pleasing light of a pink color.

CHAPTER VII

THE DEVELOPMENT OF ELECTRO-CHEMISTRY

THE striking effects brought about by electricity formed the subject of much study about the middle of the eighteenth century. At that time friction electrical machines were in use, and in order to intensify the effects produced, very large machines were constructed. The most famous of these is still to be seen in the Teyler Museum in Haarlem. Pater Beccaria, some one hundred and thirty years ago, by using such machines found that metals could be "revivified" (*i.e.*, reduced) from their calces (oxides) when the electric spark was passed between two pieces. In this way he obtained zinc and mercury. Some time later Priestly investigated the action of the electric spark on air and observed that an acid was produced; he mistook this for carbonic acid, until Cavendish recognised it as nitric acid. Van Marum studied the behavior of several other gases in this path of the electric spark (which led him to notice the formation of ozone), and made experiments also by passing the spark through liquids. Before him, Priestley had discovered that in oil and ether the electric spark produces gas, and proved that this gas contained hydrogen.

The first actual electrolysis was made by Deimann and Paets van Troostwyk in Haarlem in 1789, in which they successfully decomposed water into hydrogen and oxygen. In their experiments the water was contained in a cylindrical tube closed at the top, and having a metal wire

sealed into its upper end. Another metal wire was introduced into the lower end of the tube, which dipped into a basin of water. When the sparks struck through the water, bubbles of gas were disengaged from the metal wires, and, rising in the tube, gradually displaced the water. As soon as the column of water sank below the upper electrode the gas, which was a mixture of hydrogen and oxygen, exploded. This experiment was later repeated by Ritter, using silver wires and a solution of a silver salt, and he observed that the negative pole became coated with precipitated silver. On changing the poles, silver was dissolved from one and deposited on the other (now the negative pole). In Deimann's experiment, oxygen and hydrogen were simultaneously formed both at the positive and at the negative poles, so that the process was not a true electrolytic one like that of Ritter's.

The whole state of the science was changed in a great degree by the discoveries of Galvani, and particularly by those of Volta. In 1795, Volta arranged the metals in a series according to their behavior in galvanic experiments, and in 1798 Ritter showed that the same series is obtained when the properties of the metals to separate other metals from their salt solutions are compared.

"After the introduction of Volta's pile (in 1800) the physiological and optical phenomena were less studied," remarks Sven Arrhenius in his 'Text Book of Electric Chemistry,' "and more attention was paid to the chemical actions. As opposed to the electrical machines, these piles gave large quantities of electricity at a comparatively low potential. Nicholson and Carlisle, in 1800, studied the evolution of oxygen and hydrogen in salt solutions at immersed gold electrodes which were connected with the poles of a voltaic pile, and observed that litmus in the neighborhood of the positive pole was turned red by the acid produced there.

"Some years later Davy made his brilliant electro-chemical discoveries. He succeeded in decomposing the oxides

of the alkali and alkaline earth metals, which had previously been regarded as elementary substances, and in preparing the pure metals. Further progress in obtaining the more difficultly reducible metals in this way was later made by Bunsen and his pupils."

At the time of Davy's discovery of the alkali metals Berzelius was just beginning his scientific investigations. In one of the first of these, carried out jointly with Hisinger, he studied the action of the electric current upon solutions of various inorganic substances, resulting chiefly in the establishment of the first electrochemical theory. This theory dominated the science of chemistry for many decades. According to it, each chemical atom, when in contact with another, possesses, like a magnet, an electropositive and an electronegative pole. Moreover, one of these poles is usually much stronger than the other. Consequently, an atom behaves as if it possessed but one pole, either electropositive or electronegative, according as the positive or negative pole, respectively, predominates in strength. The magnitude and sign of this resultant polarity upon the atoms of a given element determines its chemical behavior. If, for instance, the atoms of an element are electropositive, it will react with elements whose atoms are electronegative, and conversely. During this reaction the two kinds of electricity neutralize each other, more or less completely according to the degree of inequality existing between the positive and negative charges upon the reacting atoms. If complete neutralization does not take place the resulting compound itself is electropositive or electronegative according as the electropositive are greater or less than the electronegative charges upon the component atoms. Compounds which thus possess a resultant polarity may then enter into further combinations with each other, in such a way as to form a complex compound which is more nearly or quite neutral. Thus the theory explains not only the formation of simple compounds from their elements, but also the forma-

tion of complex compounds, such as double salts, from their component simple compounds. According to this theory, chemical and electrical processes are closely related, and all compounds have a dualistic nature, being formed of an electropositive and an electronegative component. This theory is therefore known as the electrochemical or dualistic theory. It was applied throughout the domain of inorganic chemistry, which at that time was practically the entire science of chemistry, and altho it contained many arbitrary assumptions it performed a great service to science because of its systematizing influence.

For several decades after the establishment of the dualistic theory no considerable advance was made in electrochemistry. This lack of progress was soon counterbalanced by the important discoveries which were made by Faraday about the year 1835. He was the first to show that whether electricity is produced by friction or by means of a voltaic pile it is capable of producing the same effects. This fact convinced him that there exists but one kind of positive and one of negative electricity. He next attempted to discover a relation between the quantity of electricity flowing through a circuit and the magnitude of the chemical and magnetic effects which it could produce. His results may be expressed as follows:

The magnitude of the chemical and magnetic effects produced in a circuit by an electric current is proportional to the quantity of electricity which passes through the circuit.

A further discovery was made by Faraday by comparing the quantities of different substances in solution which are decomposed by the same quantity of electricity. This comparison may be made in a very simple manner by connecting into one circuit a series of solutions of different substances so that the same quantity of electricity passes through each solution. The chemical decomposition produced by the electric current in each solution may

then be determined by analysis. The results obtained may be summarized as follows:

The quantities of the different substances which separate at the electrodes throughout the circuit are directly proportional to their equivalent weights, and are independent of the concentration and the temperature of the solutions, the size of the electrodes, and all other circumstances.

Those who first recognised the decomposition of water by the electric current sought an explanation for the simultaneous appearance of hydrogen at one electrode and of oxygen at the other. It was not until 1805, however, that a comprehensive theory for this phenomenon was put forward. During that year such a theory was published by Grotthus. According to this theory the electric current charges one electrode positively and the other negatively, and these charged electrodes then exert an electrical influence upon the water molecules. Under this influence the water molecules acquire a polarity, the hydrogen atom becoming charged with positive and the oxygen atom with negative electricity. The positive electrode then attracts the negatively charged oxygen atom, and the negative electrode the positively charged hydrogen atom, causing the water molecules to arrange themselves in a row or chain.

As science gradually developed, the imperfections of the theory advanced by Grotthus became more and more apparent. According to this theory the splitting of the molecule, which is necessary for the conduction of electricity, cannot take place until the electromotive force is sufficiently great to overcome the affinity or cohesion between the two components of a given compound. As a matter of fact, however, it was found that, under suitable conditions of experiment, it is possible to cause an electric current to pass through a solution even when the electromotive force of the current is extremely small.

Clausius was the first to direct attention to the dis-

agreement of the Grotthus theory or conception of electrolysis with facts. Basing his conclusions upon the experimental results already obtained, he declared "every assumption to be inadmissible which requires the natural condition of a solution of an electrolyte to be one of equilibrium, in which every positive ion is firmly combined with its negative ion, and which at the same time requires the action of a definite force in order to change this condition of equilibrium into another differing from it only in that some of the positive ions have combined with other negative ions than those with which they were formerly combined. Every such assumption is in contradiction to Ohm's law."

At about the same time that Clausius advanced this theory Hittorf began work upon the migration of the ions, and a little later Kohlrausch commenced experiments upon the electrical conductance of solution. The work of these investigators greatly increased the knowledge of the process of electrolysis. Making use of their work, Arrhenius, in 1887, replaced the theory of vibrating ions of Clausius by the theory of free ions.

According to the material conception of electricity, an ion may be considered to be a compound of positive or negative electrons with the element in question. The formation of an ion is, then, entirely analogous to the formation of a compound from two ordinary elements. For instance, in the formation of ions from sodium iodide the sodium atoms combine with positive and the iodine atoms with negative electrons. This conception is very comprehensive, for according to it the law of electrochemical change (Faraday's law) appears as a consequence of the laws of definite and multiple proportion. Altho the theory of electrolytic dissociation was not spared great opposition in its early years, it has successfully advanced until at the present time by far the greater number of investigators accept it and recognise its value.

"It would be impossible to give in a few words a clear

conception of all the reasons which led Arrhenius to adopt his now almost universally accepted views," says Langbein in his 'Electro-Deposition of Metals,' "and a short statement of these views must, therefore, suffice. He discovered that according to the degree of dilution and the nature of their combination, salts in aqueous solutions are to a more or less far-reaching extent decomposed into independent portions, *i.e.*, the ions, and the term electrolytic dissociation is applied to this phenomenon.

"Only combinations which dissociate—are decomposed and thus form ions—can be conductors of the current, the progressive motion of the latter being solely taken care of and effected by the ions. The ions are supposed to be charged with a certain quantity of electricity—the kathions with positive, the anions with negative, electricity—and so long as current passes through to the electrolyte, they move free in the latter. However, when a current is conducted through the electrolyte, the ions are attracted by the electrodes, the positively-charged kathions by the negatively-charged cathode, and the negatively-charged anions by the positively-charged anode. By reason of these movements of the ions to the electrodes this phenomenon is called migration of the ions.

"The ions, on reaching the electrodes, are freed of their charge, *i.e.*, they yield their electricity to the electrodes. They lose thereby their ion nature, being transformed by their separation on the electrodes into the allotropic or isomeric form of the element or combination."

After the true action of Volta's pile had been discovered, the first modification was to immerse the plates of copper and zinc in the liquid. This arrangement gave a more powerful and lasting effect than the original pile. Volta arranged the cells in a circle and called such a battery a "crown of cups." In 1806, the Royal Institution of London became possessed of a battery of 2,000 elements on the trough system. It was with this apparatus that Davy succeeded in decomposing potash and soda.

This simple type of cell would, however, only work for a short time on account of the collection of bubbles of gas on the plates; *i.e.* the cells became "polarized." Becquerel studied this effect and succeeded in overcoming it to a great extent in 1829, by employing two different liquids separated by a porous partition, each of which enclosed one of the electrodes. In 1863, Professor Daniell invented the cell known by his name and which is one of the most constant current cells ever made, altho not so powerful as some. The zinc and copper electrodes are here separated by a jar of porous earthenware, the zinc being surrounded by dilute sulphuric acid and the copper by a saturated solution of sulphate of copper. This latter solution is the "depolarizer," acting to prevent the bubbles of hydrogen from collecting on the copper phate, as would be the case in the simple cell. Instead of hydrogen being thrown out at the copper pole, copper is deposited from the sulphate of copper depolarizer so that this solution becomes constantly weaker and the copper heavier. To prevent the weakening of the sulphate crystals are added occasionally. This battery has been much employed in telegraphic work. A form of this cell, known as the "gravity" cell, has been much used for this purpose, the porous partition having here been done away with, and the separation of the liquids effected by the difference in their densities.

In 1839, Grove introduced a cell in which the depolarizer was strong nitric acid, which surrounded a platinum plate. This is a much more powerful depolarizer than sulphate of copper and the cell was very energetic. It had, however, the disadvantage of high cost and gave off disagreeable fumes. The first drawback was overcome by Professor Bunsen, in 1843, who substituted for the platinum plate one of gas-retort carbon. The fumes, however, still remained. This battery was useful to the early experimenters, as it furnished a strong and constant current.

Another good depolarizer is chromic acid. This is used

in the same manner as nitric acid in the carbon-zinc cell of Bunsen. It does not, however, give off fumes and yet is almost as powerful as the Bunsen cell. Various forms of this cell have been made and they have been extensively used, especially for telephone work. They deteriorate only slightly on standing.

Perhaps the most extensively used primary cell is the LeClanche. This is also a zinc-carbon cell, but sal-ammoniac is used to replace the sulphuric acid of the preceding cells and the depolarizer is the black oxide of manganese. This depolarizer is slow in its action and the cell is, therefore, not good for constant current work, but it has a very slow rate of deterioration. This cell is very extensively manufactured in the "dry" form in which the exciting fluid is held as a moist paste. The cell is not entirely dry, however, as is sometimes supposed, for if it dries out it ceases to work.

One of the most recent primary cells as well as the best is the zinc-copper-oxide cell of Lalande. In the Edison form of this cell, the copper oxide is pressed into plates and mounted in the cell between two zinc plates. The exciting fluid is caustic potash. The copper oxide acts as the depolarizer and is reduced to metallic copper. The cell is very efficient, has a long life, and does not deteriorate on standing. Thousands are now in use for such work as operating railway signals, sparking gas engines, etc.

The existence of secondary currents was discovered by Ritter in 1803. Having substituted to the actions of a Volta's pile another pile formed only of disks of copper, separated by moist cloth, he remarked that this second pile, though inactive by itself, gave in its turn an electric current, in the opposite direction to the current of the first pile.

This current was of but short duration, and the electromotive force was lower than that of the pile used in charging it. In 1826, De la Rive also found that a secondary

or inverse current could be obtained from plates of platinum upon which oxygen and hydrogen had been disengaged in the experiment of the decomposition of water by a battery. This phenomenon took the name of 'polarization of the electrodes' and the current itself that of the 'current of polarization.'

After that, secondary currents were the object of many researches made by physicists, among whom may be mentioned Faraday, Grove, Wheatstone, Poggendorff, E. Becquerel and Gaugian. In 1859, Gaston Plante studied the influence of different metals and different liquids on the production of secondary currents, and on their intensity. Since that date the question has assumed great importance, having received scientific and practical applications, due mainly to the researches of this acute observer.

He experimented on voltameters with wires of copper, silver, tin, aluminum, iron, zinc, gold and platinum, and for each of them varied the nature of the liquid into which the electrodes were placed. He found that "all the metals oxidizing at the positive pole of the cell, the secondary current, obtained after the interruption of the primary current, was as much more intense as the oxidation was more complete, if the oxide formed remained adherent and insoluble in the acidulated liquid of the voltameter." Even gold and silver did not resist the action of the oxygen of the pile; they were covered with dark deposits of oxide, and furnished an energetic secondary current. Platinum did not oxidize, it is true, in a visible manner, but the secondary inverse current was of shorter duration than that of the metals which were covered with a layer of adherent oxide; an effect which was explained by the rapid decomposition of the oxygenated water produced around the positive electrode of the voltameter. The action of the hydrogen was, on the other hand, stronger with platinum than with all the other metals, for the electrode around which this gas was disengaged furnished, with an-

other neutral electrode, a more intense secondary current than when any other metal was employed.

The most important result of these interesting researches is that which assigns the greatest intensity to the secondary current produced by a voltameter with electrodes of lead, and dilute sulphuric acid as the liquid. Measuring the electromotive force developed in such a voltameter, after the rupture of the primary current, Plante found that it was equal to about one and a half times (more exactly, 1.48-1.49) that of the most energetic voltaic element, such as a Grove or Bunsen. This suggested the idea of constructing secondary cells, and uniting them in a battery, so as to store up or accumulate the work of the voltaic pile, in the same way that static electricity is condensed by the aid of conductors of great surface separated by an insulating material.

The action in a storage cell is as follows. When the battery is charged the positive plate consists of lead peroxide and the negative of pure lead in a spongy condition. When the cell discharges, both plates become a form of lead sulphate. Upon being charged by having a reverse current sent through them, they are reformed into lead peroxide and sponge lead. If the plates were platinum, oxygen would be given off where the current enters and hydrogen where it leaves, but with the lead sulphate plates the oxygen and hydrogen combine, thus oxidizing one and reducing the other.

Storage cells have many uses. They are employed in large sizes in central power stations to equalize the load on the machinery, serving to help the engines carry the maximum loads so that they are not strained. Electric automobiles are largely used, but the weight of the battery seriously handicaps their other excellent qualities. They also find application in lighting trains, operating industrial locomotives, supplying telephone lines and igniting gas engines.

CHAPTER VIII

THE TELEPHONE

In 1854 a Frenchman, Charles Bourseul, predicted the transmission of speech, and outlined a method correct save in one particular, but for which error one following his directions could have produced a speaking telephone. His words at this date seem almost prophetic:

"I have asked myself, for example, if the spoken word itself could not be transmitted by electricity; in a word, if what was spoken in Vienna may not be heard in Paris. The thing is practicable in this way:

"Suppose that a man speaks near a movable disk, sufficiently flexible to lose none of the vibrations of the voice; that this disk alternately *makes and breaks* the connection from a battery: you may have at a distance another disk which will simultaneously execute the same vibrations."

The words "makes and breaks" in Bourseul's quotation have been italicized by the present writer. They form the keynote of the failures of those who subsequently followed Bourseul's directions literally.

Philip Reis, a German inventor, constructed what he called a telephone in 1861, following implicitly the path outlined by Bourseul. He mounted a flexible diaphragm over an opening in a wooden box, and on the center of the diaphragm fastened a small piece of platinum. Near this he mounted a heavy brass spring, with which the platinum alternately made and broke contact when the diaphragm was caused to vibrate. These contact points

formed the terminals of a circuit containing a battery and the receiving instrument. His receiver assumed various forms, prominent among which was a knitting needle wrapped with silk-insulated copper wire and mounted on a cigar box for a sounding board. Its operation was as follows:

The sound waves set up in the air struck against the diaphragm of the transmitter, causing it to vibrate in unison with them. This caused the alternate making and breaking of the circuit at the point of contact between the platinum and the spring, and allowed intermittent currents to flow through the receiver. These caused a series of sounds in the knitting needle by virtue of 'Page's effect.' The sounding board vibrated in unison with the molecular vibrations of the needle, and the sound was thus greatly amplified.

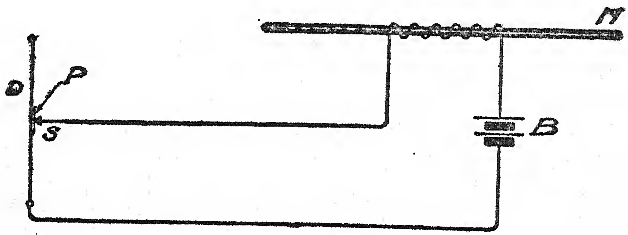


Fig. 31 —CIRCUIT OF REIS TELEPHONE. (From Miller's American Telephone Practice.)

Reis' telephone could be depended upon to transmit only musical sounds. The question as to whether it actually did transmit speech has been the subject of much discussion, but if it did this at all it was very imperfectly. "The cause of its failure," says K. B. Miller in his 'American Telephone Practice,' "to successfully transmit speech will be understood from the following facts: A simple musical tone is caused by vibrations of very simple forms, while sound waves produced by the voice in

speaking are very complex in their nature. Sound possesses three qualities: pitch, depending entirely on the frequency of the vibrations; loudness, depending on the amplitude of the vibrations; and timbre, or quality, depending on the form of the vibration. The tones of a flute and a violin may be the same as to pitch and loudness and yet be radically different. This difference is in timbre, or quality."

Reis' transmitter, as he adjusted it, was able only to make and break the circuit, and a movement of the diaphragm barely sufficient to break the circuit produced the same effect as a much greater movement. The current

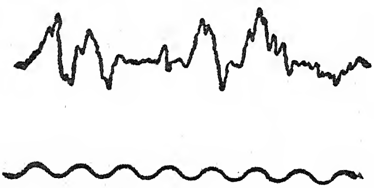


Fig. 32 —Sound Waves of Voice and Simple Musical Note. (From Miller's American Telephone Practice.)

therefore flowed with full strength until the circuit was broken, when it stopped entirely. The intermediate strengths needed for reproducing the delicate modulations of the voice were entirely lacking. This apparatus could therefore exactly reproduce the pitch of a sound, but not its timbre and relative loudness. For the next fifteen years no apparent advance was made in the art of telephony, altho several inventors gave it their attention.

In 1876 Professor Alexander Graham Bell and Professor Elisha Gray almost simultaneously invented successful speaking telephones. Gray has been one of the principal claimants for the honor of being the first inventor of the telephone, but Bell has apparently established his right to it, and has also reaped the profit, for, after long litigation, the United States Patent Office and the courts

have awarded the priority to him as against Gray and many others.

Bell possessed a greater knowledge of acoustics than of electrical science, and it was probably this that led him to appreciate wherein others had failed. His instrument consisted of a permanent bar magnet having on one end a coil of fine wire. In front of the pole carrying the coil a thin diaphragm of soft iron was so mounted as to allow its free vibration close to the pole.

"Two points will be noticed," says Miller in the work before cited, "which have heretofore been absent; that no

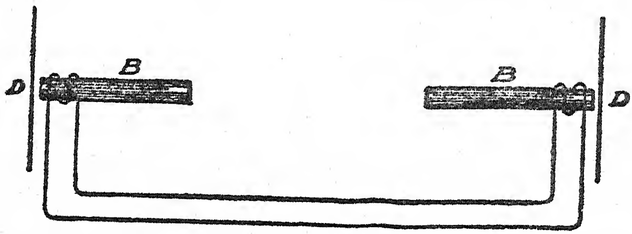


Fig. 33.—Bell Telephone as Transmitter and Receiver. (From Miller's American Telephone Practice.)

battery is used in the circuit and that the transmitting and receiving instruments are exactly alike. When the soft-iron diaphragm of the transmitting instrument is spoken to, it vibrates in exact accordance with the sound waves striking against it. The movement of the diaphragm causes changes in the magnetic field in which lies the coil, which changes, as already pointed out, cause currents to flow in the circuit. These currents flow first in one direction and then in the other, varying in unison with the movements of the diaphragm, the waves being very complex as represented graphically. Passing along the line wire, these electrical impulses, so feeble that only the most delicate instruments can detect them, alternately increase and decrease the strength of the permanent mag-

net of the receiving instrument, and thereby cause it to exert a varying pull on its soft-iron diaphragm, which, as a result, takes up the vibrations and reproduces the sound faithfully."

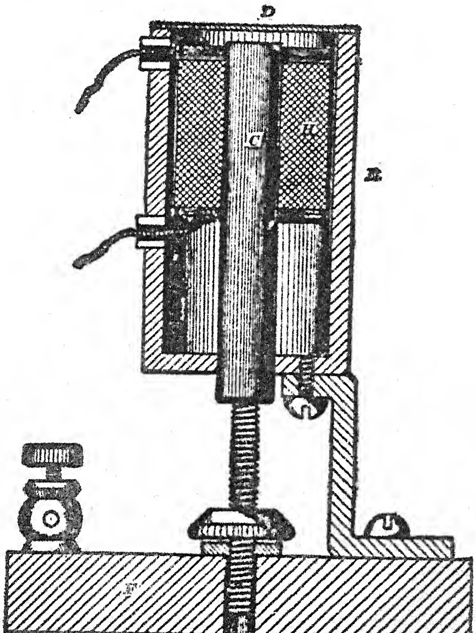


Fig. 34 —Bell's Centennial Receiver. (From Miller's American Telephone Practice.)

Bell's earlier instruments were exhibited in 1876 at the Centennial in Philadelphia. The receiver consisted of a tubular magnet, composed of a coil of wire, surrounding a core, and inclosed in an iron tube, which was about 1¾ inches in diameter and 3 inches long. This tube was closed by a thin iron armature, or diaphragm, which rested

loosely on the upper face of the iron tube, the length of the core being such as not quite to touch the diaphragm when in this position. The whole was mounted on a base, arrangements being made to adjust the air gap between the pole of the core and the diaphragm by means of a thumbscrew.

The transmitter consisted of an electromagnet in front of the core, on which was adjustably mounted a diaphragm of goldbeater's skin carrying a small iron armature at its center. A long mouthpiece, into which the sounds to

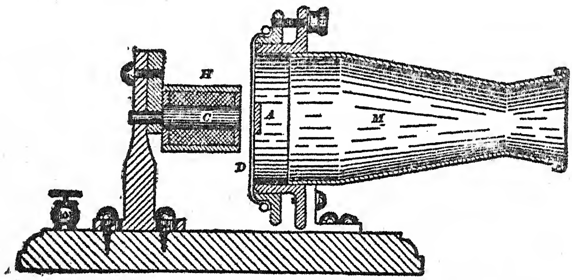


Fig. 35 —Bell's Centennial Transmitter. (From Miller's American Telephone Practice.)

be transmitted were spoken, served to convey the sound waves more directly to the diaphragm.

"Nearly all books and articles on telephones," says Miller, "that treat of Bell's early receiver at all, show and describe it as having the diaphragm fastened at one edge by a single small screw to the upper face of the iron tube, and sprung away from the tube at its opposite side. This mistake occurred in the first two editions of this work, and would have been in this one but for Thomas D. Lockwood, who was kind enough to call attention to it. The origin of the error is explained in the following interesting extract from a letter written by Mr. Lockwood to the writer of this book:

" 'This mistake first appeared in the account given by *Engineering* of Sir William Thomson's address to the British Association in September, 1876, and has been universally copied. The origin of the mistake is very odd. The screw of the instrument given to Sir William Thomson, and which he exhibited in England on his return, was put through a hole in the edge of the diaphragm and engaged with a threaded hole of the tube, for the purpose of attaching the diaphragm while in transit, to prevent it from getting lost. No one, however, notified Sir William of this, it probably having been forgotten; and Sir William seems to have forgotten what the instrument, as he saw it in Philadelphia, looked like. Finally, in knocking about among Sir William's luggage, the free end of the diaphragm was apparently, and without doubt unintentionally, bent upward, as the picture shows. But when so bent, being at the same time rigidly fastened at the opposite edge, it would not and could not work; and when Sir William showed it in England he couldn't make it work.' "

Bell's instrument in a modified form is the standard of to-day. It is now used as a receiver only, a more efficient transmitter, depending upon entirely different principles, having been invented. In speaking of Bell's invention, Sir William Thomson, Lord Kelvin, said: "Who can but admire the hardihood of invention which devised such very slight means to realize the mathematical conception that if electricity is to convey all the delicacies of quality which distinguish articulate speech, the strength of its current must vary continuously as nearly as may be in simple proportion to the velocity of a particle of air engaged in constituting the sound?"

Much has been said and books have been written on the rights of Reis as the inventor of the speaking telephone. The validity of Bell's controlling patent was the subject of many attacks, the litigation finally reaching the Supreme Court of the United States. In the opinion of this

court (October term, 1887) the following brief but comprehensive statement is found:

"We have not had our attention called to a single item of evidence which tends in any way to show that Reis or any one who wrote about him had it in his mind that anything else than the intermittent current caused by the opening and closing of the circuit could be used to do what was wanted. No one seems to have thought that there could be another way. All recognised the fact that the minor differences in the original vibrations had not been satisfactorily reproduced, but they attributed it to the imperfect mechanism of the apparatus used, rather than to any fault in the principle on which the operation was to depend.

"It was left for Bell to discover that the failure was due not to workmanship, but to the principle which was adopted as the basis of what had to be done. He found that what he called the intermittent current—one caused by alternately opening and closing the circuit—could not be made under any circumstances to reproduce the delicate forms of the air vibrations caused by the human voice in articulate speech, but that the true way was to operate on an unbroken current by increasing and diminishing its intensity. . . . Such was his discovery, and it was new. Reis never thought of it, and he failed to transmit speech telegraphically. Bell did and he succeeded. Under such circumstances it is impossible to hold that what Reis did was an anticipation of the discovery of Bell. To follow Reis is to fail, but to follow Bell is to succeed. The difference between the two is just the difference between failure and success."

A very interesting fact, and one which might have changed the entire commercial status of the telephone industry, is that in 1868 Royal E. House, of Binghamton, N. Y., invented and patented an "electro-phonetic telegraph," which was capable of operating as a magneto-telephone, in the same manner as the instruments subse-

quently devised by Bell. House knew nothing of its capabilities, however, unfortunately for him. The instrument is provided with a sounding diaphragm of pine wood stiffened with varnish, mounted in one end of a large sound-amplifying chamber, so formed as to focus the sound waves at a point near its mouth, where the ear was to be placed to receive them. The electro-magnet adapted to be connected in the line circuit had its armature connected by a rod with the center of the wooden diaphragm. By this means any movements imparted to the armature by fluctuating currents in the line were transmitted to the diaphragm, causing it to give out corresponding sounds; and any movements imparted to the diaphragm by sound waves were transmitted to the armature, causing its movements to induce corresponding currents in the line. Two of these instruments connected in a circuit would act alternately as transmitters and receivers in the same manner as Bell's instruments.

It has been shown that in order to transmit speech by electricity it is necessary to cause an undulatory or alternating current to flow in the circuit over which the transmission is to be effected, and that the strength of this current at all times be in exact accordance with the vibratory movements of the body producing the sound.

Bell's magnetic transmitter was used as the generator of this current, as a dynamo, in fact, the energy for driving which was derived from the sound waves set up by the voice. The amount of energy so derived was, however, necessarily very small and the current correspondingly weak, and for this reason this was not a practical form of transmitter, except for comparatively short lines.

Elisha Gray devised a transmitter which, instead of generating the undulatory current itself, depended for its action on causing variation in the strength of a current generated by some separate source; this variation in current strength always being in accordance with the movements of the diaphragm.

He mounted on his horizontal vibrating diaphragm a metal needle, extending into a fluid of low conductivity, such as water. The needle formed one terminal of the circuit, the other terminal being a metal pin extending up through the bottom of the containing vessel. The vibration of the diaphragm was supposed to cause changes in the resistance of the path through the fluid on account

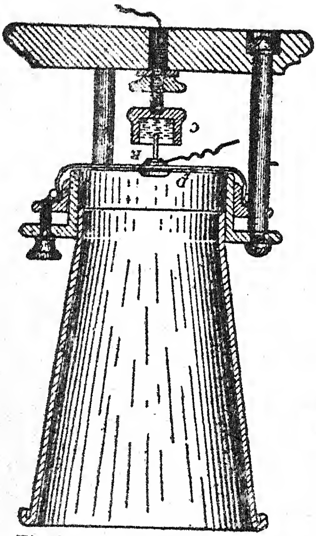


Fig. 36 —Bell's Centennial Liquid Transmitter.

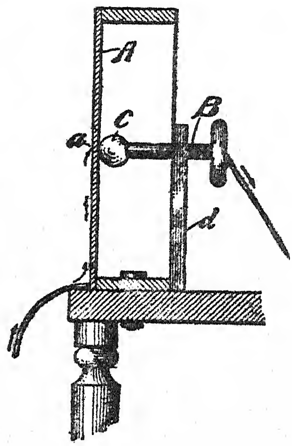


Fig 37 —Berliner's Transmitter.

(From Miller's American Telephone Practice.)

of the varying distance between the points of the electrodes and therefore corresponding changes in the strength of the current.

Bell also used a liquid transmitter in which a conducting liquid was held in a conducting vessel, forming one terminal of the circuit. The other terminal was a short

metallic needle, carried on the diaphragm, and projecting slightly into the liquid, so that the area of contact between the liquid and the needle would be varied to better advantage by the vibration of the diaphragm than if the needle were immersed a greater distance into the fluid.

Bell's liquid transmitter depended on variation in the extent of immersion of the electrode, while Gray's instrument, owing to the great extent to which the pin was immersed, depended rather on the variation in the length of the conducting path through the liquid itself, a faulty principle for this purpose.

Bell's liquid transmitter was also exhibited at the Philadelphia Centennial in 1876, and, unlike that of Reis, simply caused variations in the resistance of the circuit, and thereby allowed a continuous but undulatory current to pass over the line, the variations in which were able to reproduce all the delicate shades of timbre, loudness and pitch necessary in articulate speech.

Gray and Bell embodied, or attempted to embody, in these instruments the main principle upon which all successful battery transmitters are based. A battery furnished the current, and the transmitter, actuated by the voice, served to modulate it. It was not long, however, before a much better means was devised for putting this principle into practice.

In 1877 Emile Berliner, of Washington, D. C., filed a caveat, and later in the same year applied for a patent on a transmitter depending upon a principle pointed out in articles published in 1856, 1864 and 1874 by the French scientist Du Moncel, that if the pressure between two conducting bodies forming part of an electric circuit be increased, the resistance of the path between them will be diminished, and conversely, if the pressure between them be decreased, a corresponding increase of resistance will result.

Berliner's transmitter is shown in principle in Fig. 37, which is a reproduction of the principal figure in his now

famous patent. In this A is the vibratory diaphragm of metal, against the center of which rests the metal ball, C, carried on a thumbscrew, B, which is mounted in the standard, d. The pressure of the ball, C, against the plate, A, can be regulated by turning the thumbscrew. The diaphragm and ball form the terminals or electrodes of a circuit, including a battery and receiving instrument. The action of this instrument (which at best has never been satisfactory or commercial) is as follows: When the diaphragm vibrates, the pressure at the point of contact, a, becomes greater or less, thus varying the resistance of the contact and causing corresponding undulations in the current flowing.

Soon after this Edison devised an instrument using carbon as the medium for varying the resistance of the circuit with changes of pressure. Edison's first type of carbon transmitter consisted simply of a button of compressed plumbago bearing against a small platinum disk secured to the diaphragm. The plumbago button was held against the diaphragm by a spring, the tension of which could be adjusted by a thumbscrew.

A form of Edison's transmitter, devised by George M. Phelps in 1878, is shown in Fig. 38. The transmitting device proper is shown in the small cut at the right of this figure, and is inclosed in a cup-shaped case formed of the two pieces, A and B, as shown. Secured to the front of the enlarged head, e, of the adjustment screw, E is a thin platinum disk, F, against which rests a cylindrical button, G, of compressed lampblack. A plate of glass, I, carrying a hemispherical button, K, has attached to its rear face another platinum disk, H. This second platinum disk rests against the front face of the lampblack disk, G, and the button, K, presses firmly against the center of the diaphragm, D. The plates, F and H, form the terminals of the transmitter, and as the diaphragm, D, vibrates, it causes variations in the pressure

and corresponding changes in the resistance of the circuit, thus producing the desired undulations of current.

Professor David B. Hughes made a most valuable contribution tending toward the perfection of the battery transmitter. By a series of interesting experiments he demonstrated conclusively that a loose contact between the electrodes, no matter of what substance they are composed, is far preferable to a firm, strong current. The apparatus used in one of his earlier experiments, made in 1878, is shown in Fig. 39, and consists simply of three wire nails, of which A and B form the terminals of the

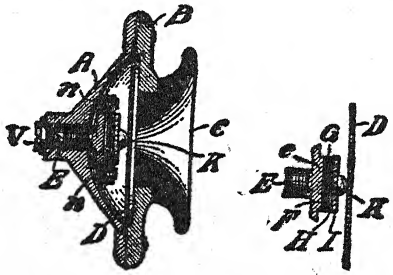


Fig. 38 —PHELPS-EDISON TRANSMITTER. (From Miller's American Telephone Practice.)

circuit containing a battery and a receiving instrument. The circuit was completed by a third nail, C, which was laid loosely across the other two. Any vibrations in the air in the vicinity caused variations in the intimacy of contact between the nails, and corresponding variations in the resistance of the circuit. This was a very inefficient form of transmitter, but it demonstrated the principle of loose contact very cleverly.

It was found that carbon was, for various reasons, by far the most desirable substance for electrodes in the loose-contact transmitter, and nothing has ever been found to approach it in efficiency and desirability.

Another form of transmitter devised by Hughes, and called by him the microphone, is shown in Fig. 39. This consists of a small pencil of gas carbon, A, pointed at each end, and two blocks, B, B, of carbon fastened to a diaphragm or sounding board, C. These blocks are hollowed out in such a manner as to loosely hold between them the pencil, A. The blocks, B, B, form the terminals of the circuit. This instrument, tho crude in form,

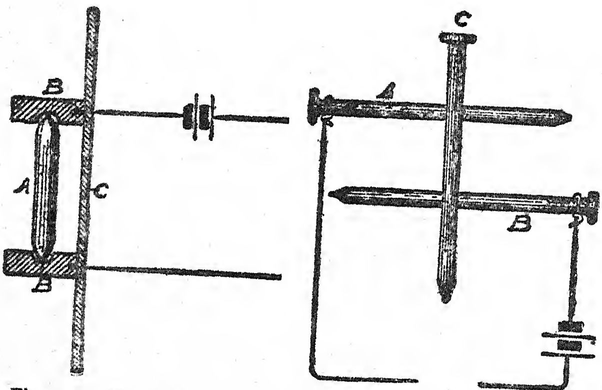


Fig. 39 —Hughes' Carbon and Nail Microphones. (From Miller's American Telephone Practice.)

is of marvelous delicacy and is well termed microphone. The slightest noises in its vicinity, and even those incapable of being heard by the ear alone, produce surprising effects in the receiving instrument. This particular form of instrument is, in fact, too delicate for ordinary use, as any jar or loud noise will cause the electrodes to break contact and produce deafening noises in the receiver. Nearly all carbon transmitters of to-day are of the loose-contact type, this having entirely superseded the first form devised by Edison, which was then supposed to depend

on the actual resistance of a carbon block being changed under varying pressure.

In speaking of Professor Hughes' work on loose contacts and the microphone, the Telegraph Journal and Electrical Review, an English electrical paper, says in its issue of July 1, 1878: "The microphone is a striking illustration of the truth that in science any phenomenon whatever may be turned to account. The trouble of one generation of scientists may be turned to the honor and service of the next. Electricians have long had sore reasons for regarding a 'bad contact' as an unmitigated nuisance, the instrument of the evil one, with no conceivable good in it, and no conceivable purpose except to annoy and tempt them into wickedness and an expression of hearty but ignominious emotion. Professor Hughes, however, has, with a wizard's power, transformed this electrician's bane into a professional glory and a public boon. Verily, there is a soul of virtue in things evil."

Professor Hughes, in an article in Nature, June 27, 1878, thus describes the conditions necessary for microphonic action: "If the pressure on the materials is not sufficient, we shall have a constant succession of interruptions of contact, and the galvanometer needle will indicate the fact. If the pressure on the materials is gradually increased the tones will be loud but wanting in distinctness, the galvanometer indicating interruptions; as the pressure is still increased, the tone becomes clearer, and the galvanometer will be stationary when a maximum of loudness and clearness is attained. If the pressure be further increased, the sounds become weaker, tho very clear, and, as the pressure is still further augmented, the sounds die out (as if the speaker was talking and walking away at the same time) until a point is arrived at where there is complete silence."

Only one radical improvement now remains to be recorded. In 1881 Henry Hunnings devised a transmitter

wherein the variable resistance medium consisted of a mass of finely divided carbon granules held between two conducting plates. His transmitter is shown in Fig. 40. Between the metal diaphragm, A, and a parallel conducting plate, B, both of which are securely mounted in a case formed by the block, D, and a mouthpiece, F, is a

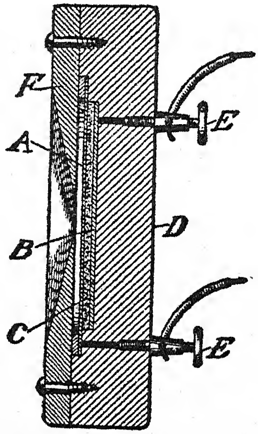


Fig. 40.—Hunning's Granular Carbon Transmitter. (From Miller's American Telephone Practice.)

chamber filled with fine granules of carbon, C. The diaphragm, A, and the plate, B, form the terminals of the transmitter, and the current from the battery must therefore flow through the mass of granular carbon, C. When the diaphragm is caused to vibrate by sound waves, it is brought into more or less intimate contact with the carbon granules and causes a varying pressure between them. The resistance offered by them to the current is thus varied, and the desired undulations in the current produced. This transmitter, instead of having one or a few points of variable contact, is seen to have a multitude of

them. It can carry a larger current without heating, and at the same time produce greater changes in its resistance, than the forms previously devised, and no ordinary sound can cause a total break between the electrodes. These and other advantages have caused this type in one form or another to largely displace all others.

At first the practice was to put the transmitter, together with the receiver and battery, directly in circuit with the line wire. With this arrangement the changes produced in the resistance by the transmitter were small in comparison with the total resistance of the circuit, especially in the case of a long line, and the changes in current were therefore small. Edison remedied this difficulty by using an induction coil in connection with the transmitter.

The induction coil used then and now is made as follows: Around a core formed of a bundle of soft-iron wires is wound a few turns of comparatively heavy insulated copper wire. Outside of this, and entirely separate from it, is wound another coil consisting of a great number of turns of fine wire, also of copper, and insulated. The transmitter, together with the battery, is placed in a closed circuit with the coarse winding of a few turns, while the fine winding of many turns is included directly in circuit with the line wire and the receiving instrument. The coarse winding is usually termed the primary winding, because it is associated with the primary source of current, the battery; while the fine winding is usually termed the secondary winding, because the currents flowing in it at the transmitting station are secondary, or induced currents. In coils of this kind the coarse winding is almost invariably termed the primary for the above reason, altho many conditions exist in electrical work and in telephone work where the high-resistance winding is in reality the primary coil.

The circuit arrangement spoken of is shown in Fig. 41, in which T is a transmitter, B a battery, P and S primary and secondary windings, respectively, of an induction coil,

L′, L′ the line wires, and R the receiving instrument. It is well to state here that the usual way of indicating the primary and secondary of an induction coil in diagraphic representation of electrical circuits is by an arrangement of two adjacent zigzag lines, as shown in Fig. 41. A current flowing in the primary winding of the induction coil produces a field of force in the surrounding space, and any changes caused by the transmitter in the strength of the current produce changes in the intensity of this

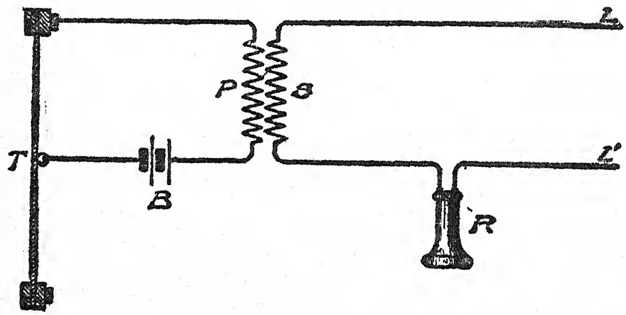


Fig. 41 —Transmitter With Induction Coil. (From Miller's American Telephone Practice.)

field. As the secondary winding lies in this field, these changes will, by the laws of Faraday and Henry, cause currents to flow in the secondary winding and through the line wire to the receiving instrument. In good induction coils the electro-motive forces up in the secondary coil bear nearly the same ratio to the changes in electromotive force in the primary coil as the number of turns in the secondary bears to the number of turns in the primary.

The use of the induction coil with the transmitter accomplishes two very important results: First, it enables the transmitter to operate in a circuit of very low re-

sistance, so that the changes in the resistance produced by the transmitter bear a very large ratio to the total resistance of the circuit. This advantage is well illustrated by contrasting the two following cases:

Suppose a transmitter capable of producing a change of resistance of one ohm be placed directly in a line circuit whose total resistance is 1,000 ohms; a change in the resistance of the transmitter of one ohm will then change the total resistance of the circuit one one-thousandth of its value, and the resulting change in the current flowing will be but one one-thousandth of its value. On the other hand, suppose the same transmitter to be placed in a local circuit, as above described, the total resistance of which circuit is five ohms; the change of one ohm in the transmitter will now produce a change of resistance of one-fifth of the total resistance of the circuit, and cause a change of one-fifth of the total current flowing. It is thus seen that fluctuations in the current can be produced by a transmitter with the aid of an induction coil which are many times greater than those produced by the same transmitter without the coil.

The second advantage is that by virtue of the small number of turns in the primary winding and the large number in the secondary winding of the induction coil, the currents generated in the secondary are of a very high voltage as compared with those in the primary, thus enabling transmission to be effected over much greater length of line, and over vastly higher resistances than would be possible if the transmitter were forced to vary the current flowing through the entire length of the line.

Neither the telephone receiver nor the transmitter have undergone any radical changes since their early days. Various minor details have received the attention of engineers and inventors, but the magneto-telephone is still the receiver and the variable resistances of the carbon contacts the means of transmission.

The principal developments have been in the means

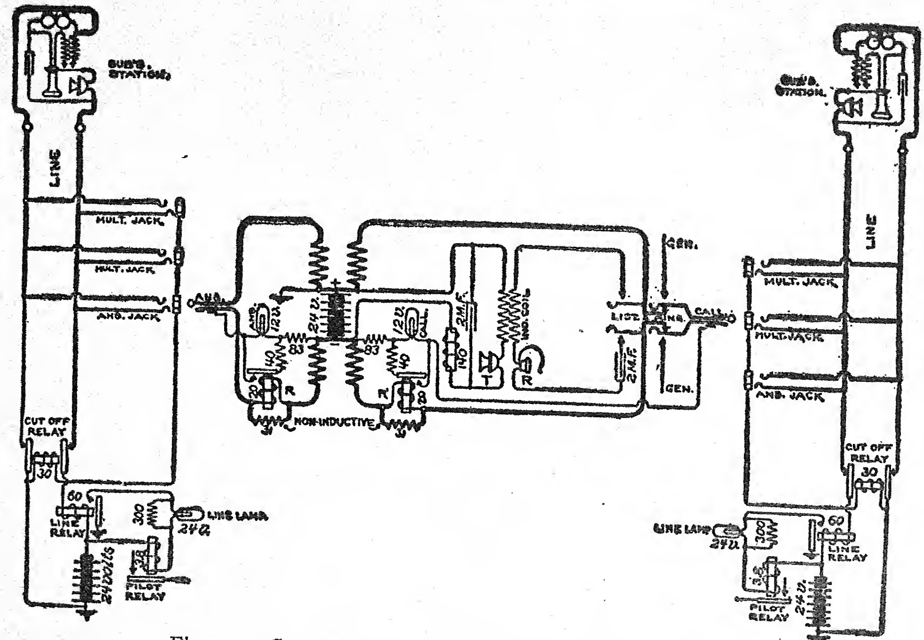


Fig. 42 —CIRCUITS OF A COMMON BATTERY SYSTEM. (From Standard Handbook for Electrical Engineers.)

of intercommunication. The growth of the telephone industry has been very rapid, and from being a luxury the telephone has become a business necessity. The tendency has been toward the simplification of the subscriber's station and the improvement of the central office. The battery current for talking is now supplied in concentrated communities from the central station. Considerable trouble formerly was experienced through the deterioration of the battery at the subscriber's station.

The telegraphone or telephonograph is an instrument which records magnetically sounds produced at a distance

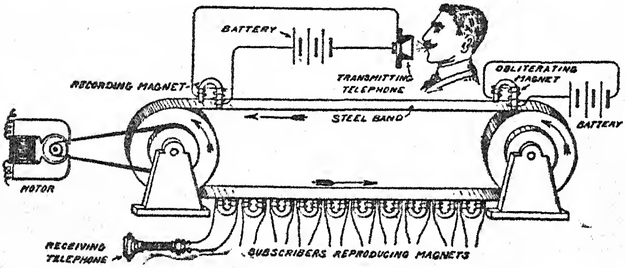


Fig. 43 —Poulsen's Telegraphone. (From Standard Handbook for Electrical Engineers.)

It was originated by Mr. Poulsen, a Danish inventor. Fig. 43 shows the essential parts. Either a steel band is used or a long steel wire rolled from one drum to the other under the recording magnet, which receives the talking currents and engraves them magnetically upon the steel wire. To reproduce the message it is only necessary to pass the steel wire under a reproducing magnet connected to a telephone receiver, the reproduction being very perfect. The message may be erased from the wire by means of the obliterating magnet supplied with an alternating current.

CHAPTER IX

ELECTRIC RAILWAYS

ALTHO the earliest recorded experiments date back three-quarters of a century, the electric railway is essentially of modern development, for it achieved a recognised position less than twenty years ago, long after the telephone, the arc and incandescent lamp, and the stationary electric motor had been thoroly established. This is but natural, for it is the logical outcome of the establishment of certain cardinal principles and practices in the kindred arts.

The first roads to carry passengers commercially were built in Europe, but the first railway experiments and the modern commercial impetus, as well as most of the essential and distinctive features of the art as it stands to-day, an example of almost unprecedented industrial development, are distinctively American, as Frank J. Sprague pointed out in his paper before the Electrical Congress of 1904, from which much of the following matter is taken.

Brandon, Vt., birthplace, and Thomas Davenport, blacksmith, father, are the names first on the genealogical tree of the electric railway, in the year 1834. A toy motor, mounted on wheels, propelled on a few feet of circular railway by a primary battery, exhibited a year later at Springfield, and again at Boston, is the infant's photograph. This was only three years after Henry's invention of the motor, following Faraday's discovery, ten

years earlier, that electricity could be used to produce continuous motion.

The records of Davenport's career, unearthed by the late Franklin Leonard Pope, show this early inventor a man of genius, deserving a high place in the niche of fame, for in a period of six years he built more than a hundred operative electric motors of various designs, many of which were put into actual service, an achievement, taking into account the times, well nigh incredible.

For nearly two score years various inventors, handicapped with the limitations of the primary battery, and in utter ignorance of the principles of modern dynamo and motor construction, labored with small result. The invention by Pacinotti in 1861 of the continuous current dynamo may properly be said to date all modern electric machines. These were developed in their earliest forms by Gramme and Siemens, Wheatstone and Varley, Farmer and Rowland, Hefner-Alteneck and others, and brought into existence the elements essential to any possible commercial success. Yet notwithstanding that the principle of the reversibility of the dynamo-electric machine and the transmission of energy to a distance by the use of two similar machines, said to have been discovered and described by Pacinotti in 1867—the same year in which Prof. Farmer described the principle of the modern dynamo in a letter to Henry Wilde—and demonstrated independently at the Vienna Exposition by Fontaine and Gramme in 1873, many years more passed before the importance and availability of this principle were generally recognised.

From 1850 to 1875 is a long period relatively, and yet there seemed to have been practically an entire cessation of experimental electric railway work until in the latter year George F. Greene, a poor mechanic of Kalamazoo, Mich., built a small model motor which was supplied from a battery through an overhead line, with track return, and three years later he constructed another model on a larger

scale. Greene seemed to have realized that a dynamo was essential to success, but he did not know how to make one and did not have the means to buy it.

Shortly afterward, in 1879, at the Berlin Exposition, Messrs. Siemens and Halske constructed a short line about a third of a mile in length, which was the beginning of much active work by this firm. The dynamo and motor were of the now well-known Siemens type, and the current was supplied through a central rail, with the running rails as a return, to a small locomotive on which the motor was carried longitudinally, motion being transmitted through spur and beveled gears to a central shaft from which connection was made to the wheels. The locomotive drew three small cars having a capacity of about 20 people and attained the speed of about eight miles an hour.

Perhaps more than to any other the credit for the first serious proposal in the United States should be awarded to Field. Curiously enough, patent papers were filed by Field, Siemens and Edison, all within three months of each other, in the spring and summer of 1880. Priority of invention was finally awarded to Field, he having filed a caveat a year before. He had been actively interested in electric telegraphs, and in an account of his work published some 20 years ago, it is stated that he early constructed two electric motors and had in mind the operation of street cars in San Francisco, but had not been able to do anything in the matter because of a realization that a dynamo must be used instead of a battery. In 1877 while in Europe he saw some Gramme machines, and on his return two of them were ordered but not delivered. Later a dynamo was ordered from Siemens Brothers in London which was lost, and this was replaced by another which arrived in the fall of 1878. Meanwhile two Gramme machines were placed at his disposal, and shortly afterward an electric elevator was operated. In February, 1879, he made plans for an electric railway, the current to be delivered from a stationary source of power through a

wire enclosed in a conduit, with rail return, and in 1880-81 he constructed and put in operation an experimental electric locomotive in Stockbridge, Mass.

Pending the settlement of patent interferences between Edison and Field (the Siemens application being late was rejected), the two interests were combined in a corporation known as "The Electric Railway Company of the United States," and the first work of the company was the operation of an electric locomotive at the Chicago Railway Exposition in 1883. This locomotive, called "The Judge," after the late Chief Justice Field, ran around the gallery of the main exposition building on a track of about one-third of a mile in length.

The motor used was a Weston dynamo mounted on the car and connected by beveled gear to a shaft from which power was transmitted by belts to one of the wheels. The current was taken from a center rail, with track return. A lever operated clutches on the driving shaft, and the speed was varied by resistance. The reversing mechanism consisted of two movable brushholders geared to a disk operated by a lever, each arm carrying a pair of brushes, one of which only could be thrown into circuit at a time, to give the proper direction of movement.

Meanwhile several other inventors were getting actively into the field of transmission of power and electric railways. In the summer of 1882 Dr. Joseph R. Finney operated in Allegheny, Pa., a car for which current was supplied through an overhead wire on which traveled a small trolley connected to the car with a flexible cable, and about the same time in England Dr. Fleming Jenkin, following a paper by Messrs. Ayrton and Perry before the Royal Institution on an automatic railway, proposed a scheme of telpherage which was developed by those gentlemen.

In the early part of the same year the writer, Mr. Sprague, then a midshipman in the United States Navy, who had in 1879 and 1880 begun the designing of motors, was ordered on duty at the Crystal Palace Electrical Ex-

hibition then being held at Sydenham, England. While in London he became impressed with a belief in the possibility of operating the underground railway electrically. He first considered the use of main and working conductors, the latter being carried between the tracks, with rail return, but noting the complication of switches on certain sections of the road, conceived the idea of a car moving between two planes, traveling on one and making upper pressure contact with the other, those planes being the terminals of a constant potential system. For practical application the lower of the two planes was to be replaced by the running track and all switches and sidings, and the upper plane by rigid conductors supported by the roof of the tunnel, and following the center lines of all tracks and switches, contact to be made therewith by a self-adjusting device carried on the car roof over the center of the truck and pressed upward by springs.

In 1882 he applied for a patent on the first idea, which was but a variation from that shown in other patents, but the second laid dormant for nearly three years because of central station work and the development of the application of stationary motors.

Meanwhile in the United States Charles J. van Depoele, a Belgian by birth and a sculptor by original trade and an indefatigable worker, had become interested in electric manufacture and soon energetically attacked the railway problem. His first railway was a small experimental line constructed in Chicago in the winter of 1882-83, the current supplied from an overhead wire. In the fall of 1883 a car was also run at the Industrial Exposition at Chicago.

A year later a train pulled by a locomotive and taking current from an underground conduit was successfully operated at the Toronto Exhibition to carry passengers from the street car system, and again in the year following Van Depoele operated another train at the same place, using on this occasion an overhead wire and a weighted arm pressing a contact up against it.

Experiments were also carried on by him on the South Bend Railway in the fall of 1885, where several cars were equipped with small motors, and also in Minneapolis, where an electric car took the place of a steam locomotive. Other equipments were operated at the New Orleans Exhibition and at Montgomery, Ala., where the current was at first taken from a single overhead wire which carried a traveling trolley connected to the car by a flexible conductor.

Other equipments were put in operation at Windsor, Ont.; Detroit, Mich.; Appleton, Wis., and Scranton, Pa.

In these several equipments the motors were placed on the front platforms of the cars and connected to the wheels by belts or chains. The cars were headed in one direction and operated from one end only.

In 1888 the Van Depoele Company was absorbed by the Thomson-Houston, which had recently entered the railway field, and Van Depoele continued in its active development until his death in 1892.

Among the early American workers of this period none was for a time more prominent than Leo Daft, who after considerable development in motors for stationary work took up their application to electric railways, making the first experiments toward the close of 1883 at his company's works at Greenville, N. J., these being sufficiently successful to be repeated in November of that year on the Saratoga and Mt. McGregor road. The locomotive used there was called "The Ampere," and pulled a full-sized car. The motor was mounted on a platform and connected by belts to an intermediate shaft carried between the wheels, from which another set of belts led to pulleys on the driving axles. A center rail and the running rails formed the working conductors. Variation of speed was accomplished by variation of field resistance, this being accentuated by the use of iron instead of copper in some of the coils.

In the following year Daft equipped a small car on one of the piers at a New York seaside resort, and a little

later another one at the Mechanics' Fair in Boston, the motor for this last being subsequently put on duty at the New Orleans Exposition. In 1885 work was begun by the Daft Company on the Hampton branch of the Baltimore Union Passenger Railway Company, where in August of that year operations were begun, at first with two and a year later with two more small electric locomotives which did not carry passengers themselves, but pulled regular street cars. A center and the running rail were used for the normal distribution, but at crossings an overhead conductor was installed and connection made to it by an arm carried on the car and pressed up against it. The driving was by a pinion operating on an internal gear on one of the axles.

Daft's most ambitious work followed when a section of the Ninth Avenue Elevated Road was equipped for a distance of two miles, on which a series of experiments were carried on during the latter part of 1885, with a locomotive called "The Benjamin Franklin." The motor was mounted on a platform pivoted at one end, and motion was communicated from the armature to the driving wheel through grooved gears held in close contact partly by the weight of the machine and partly by an adjustable screw device. This locomotive, pulling a train of cars, made several trips, but the experiments were soon suspended. This work was followed by street railway equipments at Los Angeles and elsewhere, using double overhead wires carrying a trolley carriage.

Meanwhile Bentley and Knight, after some experiments in the yards of the Brush Electric Company at Cleveland in the fall of 1883, installed a conduit system in August, 1884, on the tracks of the East Cleveland Horse Railway Company. The equipped section of the road was 2 miles long, the conduits were of wood laid between the tracks, and two cars were employed which were each equipped with a motor carried under the car body and transmitting power to the axle by wire cables.

These equipments were operated with varying degrees of success during the winter of 1884-85, but were abandoned later. This work was followed by a double overhead trolley road at Woonsocket, the motors being supplied by the Thomson-Houston Company, and later by a combined double trolley and conduit road at Allegheny, Pa.

In 1884-85 J. C. Henry installed and operated in Kansas City a railway supplied by two overhead conductors, on each of which traveled a small trolley connected to the car by a flexible cable. The motor was mounted on a frame supported on the car axle, and the power was transmitted through a clutch and a nest of gears giving five speeds. In the following year a portion of another road was equipped. A number of experiments seem to have been conducted there and on some the rails were used as a return. The collectors were of different types, and it is said that among others there was one carried on the car. The final selection was a trolley having four wheels disposed in pairs in a horizontal plane, carried by and gripping the sides of the wires; this feature, but using one wire and rail return, characterized a road installed by Henry in San Diego, Cal., opened in November, 1887.

Meanwhile work had begun in Great Britain, where the first regular road to be put in operation was that known as the Portrush Electric Railway, in Ireland, installed in 1883 by Siemens Brothers, of London. Power was generated by turbines, and the current was transmitted by a third rail supported on wooden posts alongside of the track, the running rails constituting the return. The pressure used was about 250 volts.

This was followed in the same year by a successful short road at Brighton, installed by Magnus Volk, the current being transmitted through the running rails. Then came the railway installed at Bessbrook, Newry, in 1885, under the direction of the Messrs. Hopkinson, and at Ryde in 1886, in which latter year was also installed the Blackpool road by Holroyd Smith. In this latter case the conduit

system was used with complete metallic circuit. The motor was carried underneath the car between the axles and connected by chain gearing. Fixed brushes with end contact were used for both directions of running.

Reverting to work in the United States, Sprague again took up the electric railway problem, and in 1885, before the Society of Arts, Boston, advocated the equipment of the New York Elevated Railway with motors carried on the trucks of the regular cars, and work was actually begun on the construction of experimental motors. Shortly afterward a regular truck was equipped and a long series of tests made on a private track in New York City. In May, 1886, an elevated car was equipped with these motors and a series of tests begun on the Thirty-fourth Street branch of the road.

These motors may be considered the parent models of the modern railway motor. They were centered through the brackets on the driving axles, connected to them by single reduction gears, and the free end of the motor was carried by springs from the transom, the truck elliptics being interposed between this support and the car body. The truck had two motors; they were run open; had one set of brushes and were used not only for propelling the car but for braking it. The motors were at first shunt wound, but later had a correcting coil in series with the armature at right angles to the normal field to prevent shifting of the neutral point. The car was operated from each end by similar switches, current at 600 volts was used, and increase of speed was effected by cutting out resistance in the armature circuit and then by reducing the field strength. This enabled energy to be returned to the line when decreasing from high speed. It being impossible to interest the railway management, the experiments were finally suspended. Soon afterward a locomotive designed by Field had a short trial on the same section of the elevated.

Sprague then turned his attention to building a loco-

motive car of 300 hp. capacity, each truck to be equipped with two motors, each having a pair of armatures geared to the axle, but this evidently being ahead of the times, and the possibilities of street tramway traction becoming evident, these equipments were abandoned, and he began the development of the type of motor finally used in Richmond, one crude form of which was first used in storage battery experiments in Philadelphia and others in New York and Boston in 1886.

Reviewing the conditions at the beginning of 1887, statistics compiled by T. Commerford Martin show that, including every kind of equipment, even those a fraction of a mile long and operated in mines, there were but nine installations in Europe, aggregating about 20 miles of track, with a total equipment of 52 motors and motor cars, none operated with the present overhead line or conduit, and seven cars operated by storage batteries, while in the United States there were only ten installations, with an aggregate of less than 40 miles of track and 50 motors and motor cars, operated mostly from overhead lines with traveling trolleys flexibly connected to the cars. These were partly Daft, but principally Van Depoele roads. Almost every inventor who had taken part in active work was still alive. The roads, however, were limited in character, varied in equipment and presented nothing sufficient to overcome the prejudices of those interested in transportation and command the confidence of capital.

As a result of all these experiments the series wound motor soon became universal because of its ability to start a car with the least expenditure of energy, and has held its place to the present time with minor improvements in its structure and method of gearing; 550-600 volts has become standard for the operation of the motors, this value having been found the most satisfactory. Altho higher voltages are desirable for economy of transmission, the difficulties encountered in the construction of the motors offset any advantages gained thereby.

As previously explained, the higher the voltage used, the further may the power be economically distributed. In the direct current system the voltage is limited to about 600. With this comparatively low voltage, cars could be economically operated only within a few miles of the generating station. The development of the alternating current transformer, by means of which the voltage could be raised or lowered without mechanism, showed the way to new developments. The direct current generators in the power stations were gradually removed and alternators substituted. Power could be generated at either low or high voltages, stepped up by means of transformers sent over the line at a high voltage to a sub-station, dropped to a lower voltage again by the transformers, and changed to direct current by means of rotary converters, from which the car lines were fed. This is the system at present in use in all the large cities. The most unsatisfactory part of this system is the sub-station with its rotary converter, which increases the cost of the sub-station itself and requires considerable attention.

One unfamiliar with the development of motors might ask why the cars were not equipped with alternating current motors. Motors of this class are, however, of quite recent origin, and their application to the severe strains of railway work has only been accomplished in the last four or five years. One of the most successful of these is the alternating current series motor developed by the Westinghouse Company and it promises soon to be very widely applied. The outlook for equipping long railway lines heretofore operated by steam is very promising and in fact has already begun.

In May, 1905, the Westinghouse Company completed the first heavy locomotive to be operated by single-phase alternating current. This locomotive complete weighs 136 tons. It was built in two halves, each having three axles, each axle driven by a 225-hp. single-phase series motor having single reduction gears with a ratio of 18: 95. The

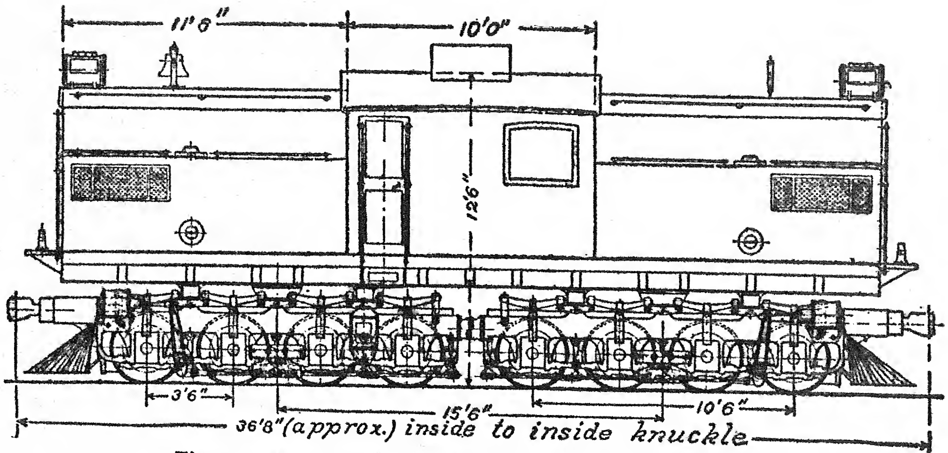


Fig. 44 —A 200,000-lb. Electric Locomotive, Heavy Freight.
(From Standard Handbook for Electrical Engineers.)

current required to operate this locomotive (6,600 volts, 25 cycles) is collected from the trolley wire by means of a pneumatically operated pantagraph trolley, with sliding contact, and carried through an oil switch and circuit breaker to an auto transformer. In this transformer it is reduced to 325 volts, at which pressure it is used in the motors. This locomotive, being designed for heavy freight service, develops a draw-bar pull of 50,000 pounds at speed of from 10 to 12 miles per hour.

Following several other successful applications of these motors, the New York, New Haven & Hartford Railroad decided to equip its road as far as Stamford, Conn., a distance of 22 miles, with the Westinghouse system. The locomotives used weigh 70 tons and are each equipped with four gearless motors of 250 hp. each. These locomotives operate over 12 miles of track in the city of New York by means of 600-volt direct current and over 22 miles of track supplied with alternating current at 11,000 volts, 25 cycles. Each locomotive is capable of hauling a 200-ton passenger train in accommodation service, requiring one stop every two miles, at a schedule speed of 26 miles per hour and a maximum speed of 45 miles per hour. In express service a maximum speed of 60 to 75 miles per hour can be attained. Perhaps the longest line yet equipped is that of the Spokane and Inland Railroad, having a total length of track of 146 miles.

It has been attempted to apply other forms of alternating current motors to railway propulsion. One of these is known as the "repulsion" motor, and altho it has been tried on short lines, it does not as yet appear to have been so successful as the "series" type. This form has also been used in Germany, where some interesting tests on high speed lines have been made during which speeds of 140 miles per hour have been recorded and 126 miles per hour with a car carrying passengers.

CHAPTER X

THE ELECTRO-MAGNETIC TELEGRAPH

As early as 1774, Lesage constructed an electric telegraph consisting of twenty-four wires, at the end of each of which was a pith-ball electroscope; and in 1816 Ronalds constructed a line of one wire, using pith-balls and two synchronous wheels. He endeavored to bring the matter to the attention of the British government, and received the really exquisite reply that "telegraphs of any kind are now wholly unnecessary, and no other than the one now in use will be adopted." A very important step was taken in 1828 by Harrison Gray Dyar, of New York, who invented a method of recording in which a discharge was made to pass through a sheet of moistened litmus paper moving at a uniform rate. A line was actually set up and experimented upon in the same year. In all of these systems it was proposed to use frictional electricity; but, even with the present vastly increased power of production and control of this species of electricity, a successfully operating telegraph would hardly be possible.

The real electric telegraph began with Galvani and Volta, and, as already intimated, more than one system has been fairly successful, the fundamental principles of which were understood before the close of the first decade of the present century. The complete solution of the problem, however, would unquestionably have been postponed for many years but for the discovery of Oersted in 1820. Immediately on its announcement, the telegraph

became the dream of many men in many countries. "Concerning its origin and growth," says T. C. Mendenhall in his 'Century of Electricity,' "the great majority of Americans have been singularly mistaken. The popular impression seems to be that it is exclusively an American invention, and that in America it was almost exclusively the product of the genius of one man. It hardly need be said that these impressions are extremely erroneous.

"Ampère, whose genius had accomplished so much in the early development of the theory of electro-magnetism, was probably the first to suggest its use in telegraphy. His method was founded on Oersted's experiment. If a needle could be deflected by an electric current, if this could be accomplished by a wire or wires of great length, and if these movements of the needle could be converted into a code by means of which letters or words could be expressed, then the electro-magnetic telegraph was possible. Ampère's suggestion was to employ a number of wires and to deflect a number of needles. Considerable attention was given to the development of this idea for a number of years following the discovery of its fundamental principle. The progress of the invention was seriously retarded by the publication of an investigation by Barlow, of the Woolwich Military Academy, in 1825, in the course of which he discovered that there was an enormous diminution in the power of a current to produce effects with an increase of distance, and which led him to declare that the project of an electro-magnetic telegraph could not possibly be successful."

The invention of the electro-magnet by Sturgeon apparently offered a new solution of the problem; but, owing to the imperfect construction of his magnets, the difficulty of overcoming distance was not diminished. This obstacle, which seemed for a time to be insurmountable, was conquered by Joseph Henry in the manner already described. Out of Oersted's experiment grew the needle-

telegraph—a form which prevailed for several years in Europe, until it gave way before the evident superiority of that founded on the electro-magnet, which grew out of the researches of Henry, and which is generally known as the Morse or American system.

The needle-telegraph was first in the field, and its working will first be considered. Many of its earlier forms appear as suggestions only, no attempt having been made to put them in practical operation. In 1832, however, Baron Schilling, a Russian counselor of state, had a working system in which thirty-six needles were used, and which included an ingenious alarm for calling the attention of the receiving operator. It consisted of a device by means of which the movement of one of the needles released a small ball of lead, which, by dropping upon the mechanism of the alarm, set it in operation. A model of this system was exhibited before the emperors Alexander and Nicholas.

A little later the two illustrious German philosophers, Gauss and Weber, established a successfully operating line at Göttingen. It was two or three miles long, and a double wire was used. Magnetic needles or bars, freely suspended, were used as receiving instruments, and the arrangement included a device for setting off an alarm-clock. The current from a battery was first used, but afterward the secondary or induced current was substituted. This line was in working order in 1833, and was established mainly for experimental purposes. The practical development of the scheme was given over to Steinheil, in whose hands it grew with rapidity. In 1837 he had constructed several miles of telegraph, extending from Munich to various points in the vicinity. His work appears to have been officially sanctioned by the government, and his wires doubtless constituted the first electric telegraph ever erected for commercial purposes. The system included a method of recording the message as received, which might also be read by sound, the signals

being distinguished from each other by the use of bells differing in pitch.

"But altogether the most valuable contribution made by Steinheil," says Mendenhall, "was the discovery that the use of a double wire was unnecessary, it being possible to establish electric communication between two points by the use of one wire, whose terminals were joined to the earth through plates of metal, or other conductors exposing considerable surface. As it largely reduced the cost of construction, this discovery was of prime importance. It was really a repetition of what Franklin had long before accomplished when he stretched his wire across the Schuylkill River, but the relation between the two experiments was not at the time appreciated or fully understood."

Both the science of electricity and the art of telegraphy owe much to the genius of Sir Charles Wheatstone, whose interest in and connection with telegraph enterprises began in 1835, in which year he exhibited one of Schilling's telegraphs in his lectures, and in the year 1837, when he formed a copartnership with W. F. Cooke, for the purpose of introducing the electric telegraph into England. Their first patent was taken out in 1837; and the system required five needles, with as many wires for their manipulation, and a sixth wire for the "return current." Wheatstone developed numerous improvements during the next few years, and as early as 1840 a dial instrument showing the letters of the alphabet was patented. Numerous difficulties were encountered and overcome, and by 1844 the enterprise was on a sound financial basis.

The operation of working a telegraph was at first naturally regarded by most people as a mystery and by many as a fraud. When communication was established between Paddington and Slough, a distance of about twenty miles, the wires were insulated partly by silk and were suspended through goose-quills attached to posts along the Great Western Railway. The telegraph company not

only invited the patronage of the public in a legitimate business way, but it also exhibited its apparatus as a novelty. This short line speedily established itself in the good graces of the people through its instrumentality in securing the arrest of a criminal.

The construction expenses incident to the use of a large number of wires, to say nothing of other difficulties, led to the reduction of the number of needles employed to two, and one in which a single wire was sufficient. A single needle is now almost universally employed wherever the needle system has survived competition with other forms. The movements of the needle are readily applied to signaling the alphabet by combinations of swings to the right and to the left. It will be remembered that in Oersted's experiment a reversal of the current through the wire reversed the direction of the deflection of the needle. The operating key is so arranged that when its handle is turned to the right a current is sent through the line which deflects the needle in the same direction; and when the opposite movement is made the current is reversed and the needle swings to the left. The alphabet may and generally does correspond with what is known as the "Morse Code." A swing to the right is interpreted as a long signal or dash, and one to the left as the short or "dot" signal of the Morse system.

For many years the needle system of telegraph was used almost exclusively in Great Britain, altho it never succeeded in gaining a foothold on the continent of Europe or in any other part of the world. Its principal advantage is the comparatively feeble current required to work it; but it is slower than the Morse system, and does not lend itself to sound-reading, or to methods of securing written records of the messages which it transmits. It has therefore almost entirely given way to other systems, even in Great Britain, altho, as will be seen, it is retained in connection with long ocean-cables, and within

a few years a self-recording device has been successfully applied to it.

The system of telegraphy now almost universally in use is one which originated in America, and whose development was nearly contemporaneous with that of the needle system. In England the fundamental experiment about which the telegraph grew was that of Oersted; while in America the electro-magnet, as constructed by Sturgeon and improved by Henry, was made the basis of the invention. As there has been much misunderstanding concerning the distribution of credit for the evolution of this system of telegraphy, it may not be out of the way to consider at some length its more important phases.

Much credit must always be accorded Professor S. F. B. Morse, through whose indefatigable labors and persistent faith the commercial value of the enterprise was first established. Born in the last century, he reached the age of forty years before having apparently given a single thought to what was to be the great work of his life. His early training was that of an artist, altho he was always fond of scientific pursuits. He studied in London under the best masters, and was highly successful in his chosen profession, some of his works bringing him great renown. His first conception of an electro-magnetic telegraph seems to have arisen out of a conversation with a friend on board the packet ship Sully, on a voyage from Havre to New York in 1832. In this conversation some experiments of the French were described, in which electricity had been transmitted through long distances. Some one remarked, "It would be well if we could send news in this rapid manner"; to which Morse at once replied, "Why can't we?" And from that moment he devoted his energies to accomplishing the desired end.

During the remainder of the voyage he made drawings of forms of apparatus and considered the transmission of signals into an alphabet. He does not appear to have been familiar with the principles of electro-magnetism at

that time, and it is affirmed that the use of an electro-magnet was suggested to him by the gentleman with whom this first discussion was held. On reaching New York, he began experimenting upon the subject, and in 1835 he had completed a working model of his recording instrument. It was not until 1837, however, that he was able to put two of them in operation at the extremities of a short line, so as to be able to both receive and send signals. In that year his apparatus was exhibited to many people in the University of New York. In the following year he made an unsuccessful effort to secure aid from Congress to establish an experimental line between Washington and Baltimore. He then visited Europe, but failed to secure patents for his inventions. During the session of Congress of 1842-43 he again struggled to secure recognition and an appropriation to enable him to build his experimental line. The scheme was considered quixotic by many members of Congress, and at the last moment he despaired of success; but during the midnight hour of the last night of the session, March 3, 1843, a bill was passed appropriating thirty thousand dollars for the line from Washington to Baltimore.

In the meantime many apparently insuperable obstacles had been encountered in the attempt to secure the successful working of the apparatus. In the beginning, Morse used a magnet with a few turns of wire, as Sturgeon had done, and a single cell of battery. With this his instrument failed to work through more than a few feet of wire. This difficulty was surmounted by taking advantage of the researches of Henry, using what he called an "intensity" magnet and many cells of battery instead of one. Altho by this method signals could be transmitted through a comparatively long distance, they were still too feeble to print themselves upon the moving strip of paper. To overcome this difficulty it was only necessary to introduce the device known as the 'relay,' by means of which the work on the main circuit was reduced

to making and breaking the current of a local battery, on the circuit of which was the recording machine. In this short circuit the current was easily made strong enough to operate the registering instrument. This method of working had been devised nearly ten years before by Henry, and it had also been used by Wheatstone in his needle system.

In Morse's first attempt to build his experimental line from Washington to Baltimore in 1844, the wires were placed underground instead of upon poles; but the former method was soon abandoned for the latter, which had already been in use for several years in Europe and elsewhere. In Morse's first instrument the 'transmitter' was mechanical; that is to say, the message to be sent was first "set up" in "dots and dashes" by arranging long and short type in proper order in a line, and by the regular movement of this line of type the circuit was closed for periods of time necessary to the reproduction of the dots and dashes at the other end. Morse did not imagine that signals could be made by the hand with sufficient regularity to produce legible records. This was soon discovered to be possible, however, and for the clumsy mechanical transmitter the simple key in use to-day was substituted, by the skilful manipulation of which the operator produces dots and dashes with such regularity and rapidity as to leave nothing to be desired.

The statements made above, derived from papers of an official character, may be summarized as follows: In the Morse telegraph are found the battery, for which credit must be given primarily to Volta, and then to Daniell, who in 1836 devised a battery nearly constant in its strength—an essential requisite to its application to the telegraph; the key, or transmitter, which, except in details of construction, is practically that in use since experiments on electricity were begun; the receiving instrument, of which the essential feature is the electro-magnet, due primarily to Sturgeon, but modified and improved so

as to be available for this work by Henry; the relay, by means of which the local current is put in operation, which was used by Henry and also by Wheatstone; the line wire suspended on poles—a method first practically used by Dr. W. O'Shaughnessy at Calcutta in 1839.

While it appears, therefore, that Morse cannot justly claim priority in the discovery of a single scientific principle involved in the telegraph, it must be admitted on all hands that he played a most important part in its development. In Europe all effort had been in the direction of the use of the needle system. Morse was quick to see the advantages of the electro-magnet, and especially the ease with which it could be made to leave a permanent record of the message. His use of a simple armature with to-and-fro motion, armed with a style, or pencil, which marked long or short lines upon a moving slip of paper, and his alphabet made up of these dots and dashes, show great ingenuity and mechanical judgment. As a measure of the value of his system, compared with the English, it is sufficient to repeat that to-day it has driven nearly every other from the field.

As the popularity of the telegraph increased and the number of line wires grew large, attempts were made to make one line wire transmit more than one message at the same time. Various schemes have been tried, most of which have failed by reason of the complications of the apparatus and the consequent troubles attending them.

The step in the direction of utilizing the line wire more fully was the invention of the duplex system by Dr. Wilhelm Gintl in 1853. This system was improved by Carl Frischen, of Hanover, until it lacked only one essential element—means to overcome the condenser-like action of the long line wire. It was not until 1872 that this was supplied by Joseph B. Stearns, of Boston, who introduced a condenser into the artificial line of the duplex system and, by adjusting it, made the artificial line behave like the line wire itself. This important addition made the

system entirely successful, so that it became possible to transmit two messages in opposite directions at the same time.

Following the success of the duplex system, there was developed a method by which two messages could be sent simultaneously in the same direction, and it was but a step to combine these two systems so that two messages could be sent each way simultaneously. This last is known as the quadruplex system, and was immediately successful because there were no delicate adjustments to be made and no rotating parts as in some of the synchronous telegraphs which have been tried from time to time.

As early as 1852 Moses G. Farmer, of Salem, Mass., devised a synchronous-multiple telegraph in which he proposed to employ two rotating switches, one at each end of the line, to successively and simultaneously join the several operators at one station with those of another. The idea was to connect two operators for an instant, pass on to the next two, and so on, returning to the first two operators so quickly that the relay of the receiving operator would not have had time to change nor the key of the sender to make a dot. The impulses of the current had therefore to be made with great frequency, and the control of this impulsive current was the principal cause of failure. Another difficulty was the maintenance of the rotating switches in synchronism.

The public is occasionally startled with an announcement that some one has invented a telegraph by which a wire may be utilized for twenty or perhaps forty transmissions, but usually it is the old wanderer in a new garb. Speed by this method, however, is limited far within the bounds of these statements. It might seem that it would only be necessary to multiply the number of contacts and to increase the velocity of the rotating arms; but the limit in this direction is soon reached, for only a certain number of impulses can be transmitted over a line within a certain period with force sufficient to pro-

duce signals. Many valuable improvements have been made in recent years in this class of telegraphy, but large as the art has grown, the great object of all has been to obtain more perfect synchronism—that is to say, to cause two mechanically independent arms to rotate at the same speed.

One of the most recent of these synchronous telegraphs and which is now being exploited is that invented by Mr. Delaney. The principle is that of Farmer, but the method used to hold the rotating switches in synchronism is extremely ingenious. It is stated that 1,000 words per minute may be transmitted over a single wire. The messages are prepared on a tape by a punching machine and received on a chemically prepared strip of paper.

The idea of printing the despatch is not new. In the early days of the electric telegraph (1841) Wheatstone took out a patent for printing the message in ordinary letters upon a strip of paper. Since then many inventors have followed out the same idea, with more or less success. The most perfect of all these systems, however, is that invented by Professor David E. Hughes, which, in a modified form, is now very generally used as a news or stock ticker. Fig. 45 shows the connections for such a telegraph.

The sending station is at A and one of the receiving stations at B. The line is fed with an alternating current produced by reversing commutator, 4. This alternating current does not affect printing relay 5, but does operate polar relay 6, which in turn operates the escapement. Reverser 4 is driven by constant-speed motor 1 and has as many segments as there are characters on the type wheel. The escape wheel 10 is provided with an equal number of teeth, so that each revolution of reverser 4 will produce one revolution of type wheel 7. On the shaft with the reverser is rigidly mounted a cylinder provided with a number of pins arranged spirally as shown; each pin is in

line with a segment of the reverser and also in line with a pin fastened to the keyboard.

Depressing a given key will always stop the cylinder and therefore type wheel 7 in the same place. The connection to the motor 1 is made with friction clutch 2, which slips when cylinder 3 is stopped. Now it is evident

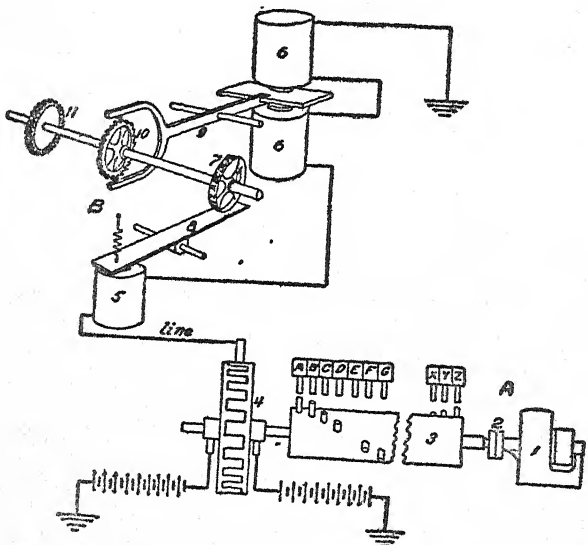


Fig. 45 —Arrangement of a Printing Telegraph or "News Ticker." (From Standard Handbook for Electrical Engineers.)

if type wheel 7 is started with its characters in certain position and is rotated by a motor through gear 11 and controlled by escapement magnet 6, that it will always remain in the same relative position with cylinder 3, and that the operator can stop the type wheel in any desired position.

If the type wheel stops because of the arrest of the cylinder 3 by depression of a key, the current ceases to alternate and magnet 5 has time to draw up its armature, 8, and press the tape against the type wheel, thus printing the character which corresponds to key depressed at the sending station.

These are ingenious arrangements for reproducing at a distant point handwriting, drawings, etc. One of the

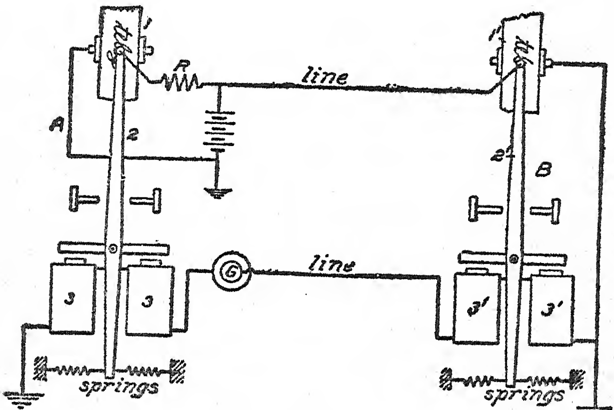


Fig. 46 —DENISON ELECTROCHEMICAL FACSIMILE TELEGRAPH. (From Standard Handbook for Electrical Engineers.)

first of these is known as Casselli's pantelegraph, because the reproduction may be of the same size or even larger than the original. The message to be sent is written with an insulating ink on a piece of tinfoil and received on a sheet of chemically prepared paper upon which a blue dot is left at each current impulse. The motions of the marking style at the two stations are controlled by similar pendulums. In the Denison system these pendulums are forced to vibrate together through the control of electro-magnets operated by the same alternating current.

The most recent and useful of these arrangements is the telautograph. The message is reproduced as fast as it is written. Drawings or sketches are transmitted with great accuracy; in fact, every motion of the sending pen is instantly followed by the receiver. Some of these are in use in the United States army.

The insulation of conductors for use under water was made possible by the discovery of gutta-percha by an English surgeon in India in 1842. It is extremely probable that the widespread use of submarine cables would have been postponed many years had this substance remained

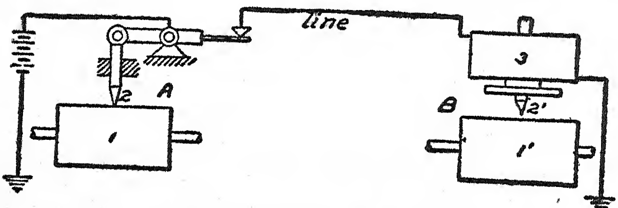


Fig. 47.—Electromagnetic Facsimile Telegraph. (From Standard Handbook for Electrical Engineers.)

unknown. One of the first cables insulated by this material, and possibly the very first, was laid in 1848 across the Hudson River, from Jersey City to New York. In 1850 a cable was laid across the channel, from Dover to Calais, but it was unprotected by any sheathing or armor, and it lasted but a single day.

In the following year the experiment was repeated, this time with a cable protected by a number of heavy iron wires. The operation was successful, and permanent telegraph communication was established. During the next few years the number of submarine cables increased rapidly, as did also their length, altho, on account of ignorance in regard to many conditions necessary to insure the best success, failures were numerous. Many people began to consider the feasibility of a line connecting the

continents across the Atlantic Ocean. A few sanguine capitalists combined to further the enterprise, and through the undaunted courage and faith of an American, Mr. Cyrus W. Field, the purely financial obstacles were surmounted. Unfortunately, the electrical and engineering problems to be met with were not understood; and the first cable of 1858, after gasping for breath for a few short weeks, lay dumb forever at the bottom of the sea.

Something of the character of this cable may be learned from the following brief description by Sir William Thomson, to whom, more than to any other one man, the world is indebted for the success of submarine telegraphy: "In the year 1857 as much iron as would make a cube twenty feet wide was drawn into wire long enough to extend from the earth to the moon, and bind several times around each globe. This wire was made into 126 lengths of 2,500 miles, and spun into 18 strands of 7 wires each. A single strand of 7 copper wires of the same length, weighing in all 110 grains per foot, was three times coated with gutta-percha, to an entire outer thickness of .4 of an inch; and this was 'served' outside with 240 tons of tarred yarn, and then laid over with the 18 strands of iron wire in long, contiguous spirals and passed through a bath of melted pitch."

An attempt to lay this cable in 1857 resulted in the loss of 400 or 500 miles by breaking from the stern of the ship from which it was run. After some further experimentation, it was determined to employ two ships to lay it in the following year; and accordingly, on the 29th of July, 1858, the Niagara and the Agamemnon, each loaded with half the cable, met in mid ocean, joined the ends, and started, the Niagara for the west and the Agamemnon for the east. On the 5th of August the ends were successfully landed on the opposite shores of the Atlantic.

The cable was known to be in bad condition before the laying was completed, and the earnest but ill-advised efforts which were made to force it to work during its brief

period of activity only tended to shorten its life. Communication of a very irregular and unsatisfactory character was maintained for several weeks. The admirable mirror galvanometer, which had just been devised by Sir William Thomson, was for the first time in use at the Valentia end, while for a time the attempt was made to use the ordinary receiving apparatus which had been provided by the company at Newfoundland. Later the galvanometer was put in use on this side, but not before very powerful currents had been used on the cable. In fact, Sir William Thomson has declared his belief that, if proper methods of handling the cable electrically had been in use from the beginning, its performance would have been lasting and in the main satisfactory.

Owing to the fragmentary character of many of the messages transmitted, a single sentence from that of the Queen to the President having been received on August 16, and the remainder twenty-four hours later, many persons in both Europe and America became skeptical as to the transmission of signals, and not a few even doubted that the cable had been laid. As a matter of fact, four hundred messages, containing over four thousand words, were sent. On September 1 interchange of messages ceased; but on October 20 the cable spoke its last words—"two hundred and forty"—which were read at Valentia, being part of a message giving the number of battery-cells then on the line. From that date the "splendid combination of matter lay at the bottom of the sea, forever useless." But it had not lived in vain; the possibility of the thing was demonstrated, and it only remained to surmount the obstacles which this trial had shown.

During a few years succeeding this first attempt, the problem was studied in the light of the experience which it had afforded. Another trial was made in 1865, this time by the Great Eastern, a vessel which offered many advantages for cable-laying. After about two-thirds of the distance was run the cable broke, and further opera-

tions were postponed until the following year, when a complete cable was successfully laid, and that of 1865 picked up, spliced and finished. Since then other lines have been placed across the Atlantic; and now the operations of laying an ocean cable attracts no attention.

One of the difficulties encountered in attempting to send messages through such a long cable was that due to the electrostatic capacity of the cable. The cable acts like a very large condenser, so that when the voltage is applied at one end the current does not instantly rise to its steady value, but takes several seconds, and when the supply of voltage is disconnected the current continues to flow. In order to signal rapidly, therefore, it was necessary to overcome this action and to use very delicate receiving instruments. For this purpose Sir William Thomson, Lord Kelvin, devised the well-known siphon recorder, which is really a sensitive galvanometer whose moving coil carries a siphon tube filled with ink, the ink being ejected from it in fine drops on a strip of paper. To produce these fine drops the siphon tube is connected to a small electrostatic machine, so that the tube is electrified.

Altho the telephone has made such rapid advances as a means of communication, the telegraph still holds its own field. The greater simplicity of the latter, the less expensive lines, the greater distances to which messages can be transmitted, all combine for its preservation. The flattening out of the waves on a telephone line due to the condenser-like action of the line has not yet been overcome. The difference between the telephonic waves at the beginning and end of a line may be compared to that between the noisy exhaust of an automobile motor without and with a muffler. In the case of the transmission of telephone waves it is, therefore, a problem of how to rid the line of its muffler.

CHAPTER XI

WIRELESS TELEGRAPHY

PROFESSOR HENRY, of Princeton University, was the first to show the oscillatory character of the discharge of a Leyden jar. This single loud spark, which to the eye seems to pass in one direction across the gap, is really a quick succession of current surges, first one way and then the other, and has its mechanical analogy in the pendulum.

At the outset it may be well to analyze this spark discharge, as it is still the most prominent means of radiating the electric waves used to transmit signals. Suppose this pendulum analogy of the spark discharge between two spheres be taken and the similarity of the two actions noted. If a heavy pendulum be drawn back by means of a light fiber, it will finally strain the fiber to such an extent as to cause it to break. The pendulum being suddenly released gradually acquires motion, which is accelerated until its lowest position is reached, after which it is retarded just as it was accelerated and stops at about the same height at which it started. The process is then repeated, but in the opposite direction. Now compare the action on the two charged spheres. The pressure in the dielectric surrounding the spheres is gradually raised until it suddenly gives way, there being a flow of current from the positive to the negative sphere, which current gradually increases and is greatest at the instant when both dielectrics are at the same potential, just as the

motion of the pendulum was greatest at its lowest position. The current then begins to decrease and finally stops when the dielectric is again strained to about the same potential it had at first but reversed in direction. The current then starts back again just as the pendulum again acquired motion.

Now let it be considered what goes on in the space surrounding this action. A current is always surrounded by a field of magnetic force, which field is proportional to the strength of the current. As this current between the two spheres increases there is, therefore, sent out an increasing magnetic field which is radiated into space, reaching a maximum and again decreasing with the current. But while the current increases the electrostatic strain about the sphere decreases, thus sending out an electrostatic wave which again increases as the current decreases. It will thus be seen that as these surges take place alternate electromagnetic and electrostatic waves are radiated into space.

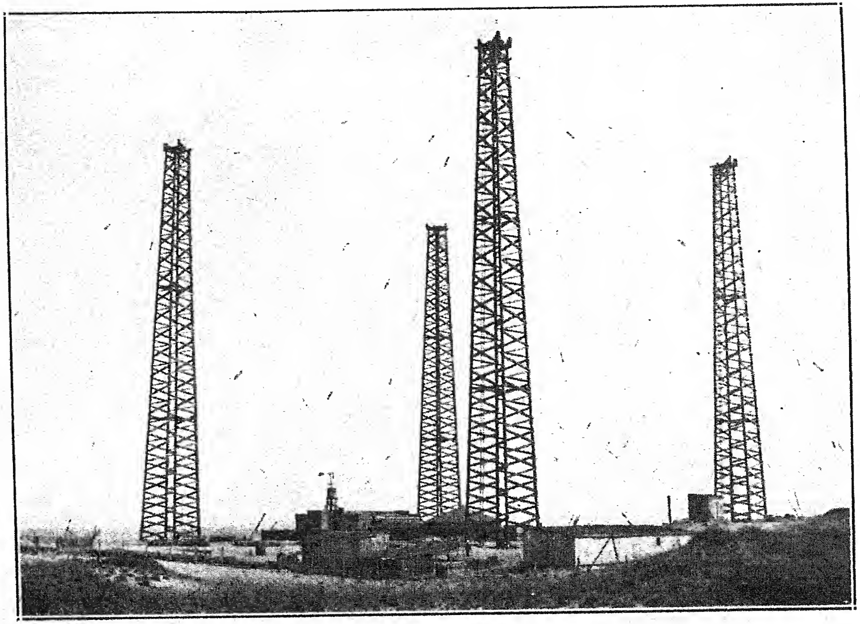
Why do not these surges keep on forever? Mainly because the current in its flow across the gap encounters a resistance, and instead of converting all its energy into magnetic waves loses a portion as heat at each surge. This corresponds to oscillating the pendulum in a liquid or viscous material, the energy of its motion soon being converted into heat.

So much for the creation of these waves. But how may their passage through space be detected? One way is by catching them on a wire. What is the manner of the catching? If a wire be placed so that it cuts the wave transversely to its line of motion, it is clear that the moving magnetic wave will induce in it an electromotive force. As these waves follow in rapid succession, a series of alternating electromotive forces is set up in the wire. These oscillatory currents are sometimes called "jigs." How these jig currents make their presence known varies with the style of wave detector used.

Before entering upon the history of this "spark telegraphy," as the Germans call it, it may be well to review some of the experiments which preceded this system. In 1838 Professor Joseph Henry, of Princeton, making with an electrical machine and Leyden jar a one-inch spark in the top room of his residence, set up induced currents in the cellar of the same building. Professor Morse, however, was probably the first to successfully transmit signals without wire. On December 16, 1842, he sent a wireless telegram across a canal eighty feet wide; and in November, 1844, L. D. Gale, acting under instructions from Professor Morse, made wireless signals across the Susquehanna River at Havre de Grâce, a distance of nearly one mile. In the latter experiment Mr. Gale used as a source of energy six pairs of plates in the form of a galvanic battery. He found that the best results were obtained when on each side of the river two plates were immersed near its bank and were connected by an insulated wire stretched along each shore for a distance three times as great as that which measured either path of the crossing signals. A few years later James Lindsay, a Scotchman, repeated Morse's experiments, but without knowing of them. In 1859 he read a paper before the British Association on the subject of "Telegraphing without Wires," and among his hearers were Faraday and Lord Kelvin.

A method of signaling without wires by means of the inductive effect of two parallel circuits was successfully used by Sir William Preece in 1882. The principle of this method is as follows: If two loops of wire are placed parallel to each other and an intermittent current is passed through one of them, waves of magnetic flux are sent out, portions of which thread the second loop and by their fluctuations produce currents in it which may be detected by a telephone or other device. The strength of such signals falls off very rapidly from the source, and such a system can only be made to operate over short distances.

Preece constructed two parallel lines, one on the Eng-



Wireless Telegraphy Station at South Wellfleet, Mass

The development of wave detectors is an important chapter. For these instruments Professor Fleming has suggested the use of the word cymoscope as a general term including all classes of wave detectors. A great number of these have been invented, but they may all be included under the following classes: 1, spark cymoscopes; 2, contact cymoscopes; 3, thermal cymoscopes; 4, magnetic cymoscopes; 5, electrolytic cymoscopes; 6, electrodynamic cymoscopes; 7, vacuum tube cymoscopes.

The first cymoscope invented was that used by Hertz in his investigation of electric waves, and belongs to the first class. It consisted merely of a ring broken at one point and arranged so that the gap might be adjusted

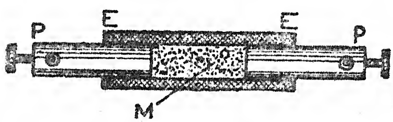


Fig. 49 —The Branley Filings Coherer.

by means of a micrometer screw. Tiny sparks across this gap indicated the presence of waves. Since the electromotive force required to produce a spark across even a small gap is very considerable, it will be obvious that such a detector could only operate at a short distance, and would, therefore, be useless for the purpose of signaling.

The next invention, made in 1890, was the Bramly coherer, Fig. 49, which consisted of a small glass tube containing two metallic plugs and separated by a gap partially filled with metallic filings. This is an example of the second class. The metallic filings, when loosely packed, offer a very high resistance to the passage of current through them, but the presence of waves breaks down their contact resistance, which continues after the waves have ceased. In order to again restore their re-

sistance they must be tapped or shaken, an operation known as decoherence. It is obvious that such an apparatus may be used like a key in a telegraphic circuit—a key operated by electric waves—and may therefore be used to operate a telegraphic instrument. Such was the first device used. It was defective, however, in that it was necessary to tap it after each signal, decoherence was not certain, it required frequent adjustment, and the result was often a confused lot of signals.

Many arrangements of loose contacts were tried, and

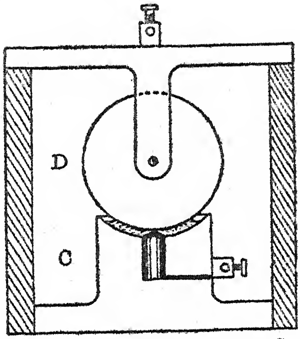


Fig. 50 —The Lodge-Muirhead Coherer.

the coherer was improved by Marconi, Lodge, Braun, and others. One of the principal troubles being the operation of decoherence, most of the inventors sought to develop a coherer which should be self-restoring, and a number of successful types were invented. One of these was the Hughes coherer, employing carbon granules placed between iron plugs. The most perfect and successful of all these is, however, that devised by Sir Oliver Lodge and Dr. Muirhead, and used in the Lodge-Muirhead system. As shown in Fig. 50, it consists of a steel disk, slightly separated from a globule of mercury by a film of oil, the disk being arranged to rotate slowly. The

presence of waves breaks down the oil film and establishes contact with the mercury, which contact immediately breaks upon the cessation of the waves. A siphon recorder, placed in series with the cymoscope, is used to record the message.

Altho a number of forms of the magnetic style of detector were devised, it was not until 1902 that a successful working apparatus was produced. For some time before that it was known that the oscillating currents received would annul wholly or in part the magnetic hysteresis of iron when passed through a coil surrounding the iron. Hysteresis acts like molecular friction, so that when a magnetizing current is passed through a coil surrounding an iron core, the magnetization does not increase and decrease with the current in the coil, but lags behind it. If another coil be placed around this same core and the oscillating currents passed through it, this hysteresis will be suddenly removed and the magnetism in the core will suddenly change in value. This sudden change could be detected by a third coil surrounding the core and connected to a telephone receiver, resulting in a sudden click. This was the principle of which Marconi made use in his magnetic detector, and which he has used in his long-distance experiments. The arrangement is shown in Fig. 18. It consists of a band of iron wires passing through two coils, one carrying the jig currents and one connected to the telephone. The wires are magnetized by two permanent magnets, and as they move under that portion where the two poles meet, the magnetic flux in them undergoes a reversal, which reversal, however, always takes place at the same point until the jig currents pass, when the flux is suddenly shifted backward, causing a sound in the telephone.

These detectors have come into very general use on account of their convenience, sensitiveness, and adaptation to rapid signaling. In 1901, Dr. Lee de Forest patented a detector which depends for its operation on the dis-

ruption of the minute metallic bridges or 'trees' which form, under suitable conditions, between the electrodes of an electrolytic cell. The apparatus, called a 'responder,' consists in a glass tube similar to that of a coherer, in which are fitted two electrodes, preferably of tin. The space between the electrodes—about 1/64 inch—is filled with a viscous, semiconducting liquid, such as glycerin with a small admixture of water, together with some peroxide of lead as a depolarizer, to prevent the excessive evolu-

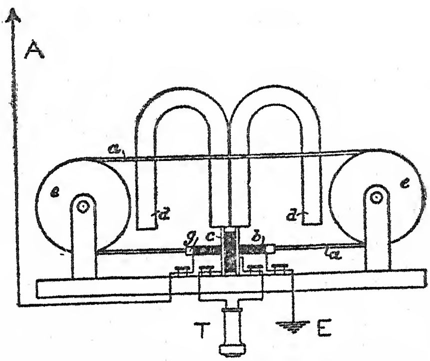


Fig. 51 —THE MARCONI MAGNETIC DETECTOR.

tion of gas. When a cell of suitable voltage is connected across this "responder," metallic "trees" or bridges are formed, which make a path of low resistance; but upon the passage of the jig currents these "trees" are broken down and the circuit broken, producing a sound in a telephone receiver. Immediately upon the cessation of the jig currents, however, these "trees" again establish themselves.

Another very successful and extremely sensitive detector was invented by Fessenden and Vreeland, and consists of a small platinum cathode containing nitric acid, with a minute anode of platinum wire 1/10000 inch

in diameter. This little electrolytic cell, when polarized to the critical point by being connected to a battery, is remarkably sensitive to jig currents. It has been employed by Fessenden in his transatlantic experiments.

Many other detectors have been developed which have operated successfully, but those described are used most generally.

It would not be possible in a few words to give a comprehensive idea of the various systems in use, as many important improvements which have been made in the last ten years. Those systems which have attained commercial importance are the Marconi, the Fessenden, the De Forest, the Slaby-Arco, and the Lodge-Muirhead. The greatest differences are usually found in the receiving apparatus.

The first system used by Marconi employed the coherer as a wave detector and the Ruhmhorff coil to produce the sparks from which the waves were radiated. The diagrammatic arrangement of the sending and receiving apparatus is shown in Fig. 52, T being the coherer and L the telegraphic relay. Experiments with this form of apparatus were first made in 1896 in England, where Marconi went to obtain the assistance of Sir William Preece. These experiments were so successful that trials were made during the next year, at each of which something new was learned whereby the distance of transmission was increased. From some of these experiments Marconi worked out the effect of the height of the antenna, or aerial wire, on the distance of transmission.

In August, 1897, Marconi organized a company known as the Wireless Telegraph and Signal Co., with a capital of $5,000,000. In June, 1897, Marconi went to Rome, and after having undertaken in this city, at the instigation of the Minister of Marine, several experiments from one floor to another with a conductor three yards in height, was invited by the Hon. Brin, Minister of Marine, to undertake, in the presence of a select commission com-

posed of officers who were specialists belonging to the royal marines, some fresh experiments. The place chosen was the Gulf of Spezzia. The experiments took place between the 11th and the 18th of July, 1897. The apparatus made use of for transmitting and receiving was similar to those employed on the Bristol Channel; that is to say, aerial wires ending above in metallic sheets. The coil was less powerful than that used in the former case, giving sparks 10 inches in length only.

The apparatus was located, during the entire series of

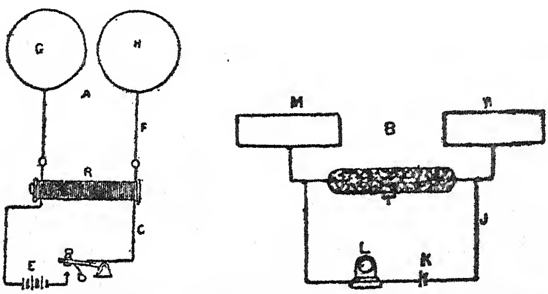


Fig. 52 —RUDIMENTARY TRANSMITTING AND RECEIVING APPARATUS.

experiments, in the electrical laboratory of St. Bartholomew, and bore an aerial line about 75 feet in height, which was afterward prolonged to 90, terminating in a square metal sheet of about 8 feet in the side.

On the first three days, viz., 11th, 12th and 13th of July, the experiments were executed on land, which gave very good results up to a distance of 3½ kilometers, or say 2 miles; on the 14th of July the receiver was set up on board a tug, having a mast about 50 feet in height, which bore an aerial wire of equal length ending in a sheet about 8 feet in the side.

The transmitting station was bound to carry out the following instructions: Ten minutes after the start of

the tug it was to send for 15 minutes dots and dashes at intervals of 10 seconds; then transmit a phrase, maintaining between each signal an interval of 10 seconds; then to suspend transmission for an interval of 5 minutes, after which it should go through the same round, but with intervals of 5 seconds instead of 10 between each signal.

The tug having started from the little port of St. Bartholomew, the receiver registered some signs even before transmission had begun on land, a fact due doubtless to extraneous causes. She directed her course toward the western mouth of the mole, and continued to receive signals, not, however, in the order and in the intervals that had been prearranged, but much more frequently. The sky was covered with stormy clouds and in the distance lightning was frequent, hence it was surmised that besides the signals that were really transmitted, others, due to atmospheric influence, were impressing themselves, which rendered the strip of paper on which they were registered illegible.

On again repeating these experiments after the storm clouds had disappeared, correspondence came out very clearly up to a distance of 5,500 meters (nearly 3 miles), with the tug stationary. The tug was again put in motion, so as to interpose between itself and the station at St. Bartholomew the point called Le Castagne, in order to ascertain what effect such a screen would have on signaling.

The signals ceased as soon as the obstacle intervened, to recommence on the tug being moved from its influence. On the return journey the messages continued to come out clear and exact.

On the 17th of July trials were made from the same stations of St. Bartholomew to the armored ship San Martino, anchored at a distance of about 1¾ miles from the transmitting station, the aerial conductor of which had been carried to a height of about 40 yards, while the

ship bore at the receiver an aerial line, first of 20, and then of 30 yards in height.

Transmission succeeded perfectly, independent of the position of the coherer and the receiver; that is to say, even if they were screened at the sending station and surrounded by metallic masses under cover or placed below the water-line in the ship.

It was at once foreseen by many experimenters, among them Sir Oliver Lodge, that with the old forms of apparatus there would be interference between wireless stations, as the receivers would respond to all wave lengths. To understand how it is possible to make a sending or a receiving circuit which will send out or respond to only one kind of electric wave, let the pendulum analogy again be used. In order to set a pendulum in motion it is necessary that the impulsive force should be imparted to it the same number of times per second in which the pendulum naturally oscillates. Even if stray forces are applied, but are not properly timed, the effect on the pendulum will be small, whereas a very minute but properly timed force, acting for some time, will produce considerable motion in a large pendulum. All these characteristics of the pendulum may be applied to the electric circuit—the natural period of vibration, the small effect of a lot of waves differing in length, and the large effect of a succession of feeble but similar waves.

Sir Oliver Lodge, in 1897, took out a patent for a 'syntonic' system of wireless telegraphy, based directly on his own work on the discharge of Leyden jars and on Hertz's experimental results. The transmitter consisted of two large cones of sheet metal placed with their axes in a vertical line, and having a spark-gap between their apices. In another form of transmitter a single metal sphere, separated by small spark-gaps from the terminals of an induction coil, was used as a radiator. Both types produced direct Hertzian radiation, the latter giving waves of very high frequency. The spherical oscillator

was partially enclosed in a copper cylinder, open at one end in order that the rays might be condensed in one direction. The receiver, for use in connection with the large cones, consisted of two similar cones connected through the primary of a small transformer, the secondary of which was connected to the coherer circuit. The dimensions of the transmitter and receiver were adjusted to give equifrequent natural vibrations and therefore resonance. No earth connection was made, as it was desired that the transmission should be purely by means of

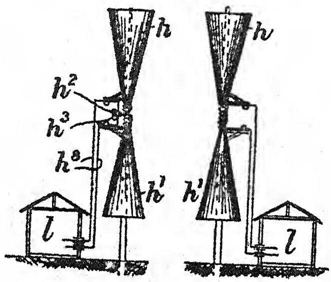


Fig. 53 —Lodge's Syntonic Method of Signaling.

free radiations. The early conical form of radiator has now given place to the horizontal conductors. Stations in which this latter arrangement has been adopted are now working in various parts of the world.

As soon as Marconi had modified his system of telegraphy he applied it immediately to the conquest of record distances in radiotelegraphic transmission. To this end he set up a station at the Lizard (Cornwall), which was immediately put into communication with Marconi's experimental station at St. Katherine's, Isle of Wight, at a distance of 300 kilometers (about 200 miles), in which he used an aerial conductor consisting of four vertical wires standing about 5 feet from one another, about 144

feet in height, along with a strip of wire netting of the same length.

Under the new system the energy required to telegraph to a given distance was very much diminished, so that 150 watts sufficed to communicate to the 300-kilometer distance.

Encouraged by the results of the experiments in communication between St. Katherine's and the Lizard, Marconi put his whole heart into the attempt to resolve the arduous problem of establishing transatlantic radiotelegraphic communication. Repeated experiments had shown that long waves, either by successive reflection or diffraction, could turn round the surface of the earth, so that their transmission to very great distances resolved itself only into a question of sufficient power in the transmitting apparatus and sufficient sensibility in the receiving; but these necessitated large financial means, which would, however, not be wanting in a man whose business acumen was not less surprising than his experimental ability.

Being largely subsidized by the Marconi Wireless Telegraph Company, Marconi began, early in 1901, unknown to every one, his trials, by establishing two specially powerful stations at Poldhu, near Cape Lizard, in Cornwall, on one side of the ocean, and at Cape Cod, in Massachusetts, on the other side. The results of these first trials are not known, and judging by the silence maintained in this regard they were probably negative. The two stations, that had cost the sum of more than £15,000, were destroyed by storms in September of the same year.

Marconi caused the station at Poldhu to be rebuilt, furnishing it with powerful machines and radiators, and decided to attempt communication with St. Johns, Newfoundland; that is to say, to a lesser distance than that previously chosen, viz., of about 1,500 miles. At St. Johns, Newfoundland, where Marconi had obtained from the Government every facility for making the trials, the

installation was of the simplest character, consisting of a receiving station only. The aerial line was maintained at a height of about 400 feet by means of a kite.

Marconi had already agreed with the station at Poldhu that every day, at six o'clock in the evening, a long series of letter S should be sent. This letter, in the Morse alphabet, consists of three dots.

The message was received telephonically. On the 12th of December, 1901, Marconi announced that he had received the different S's at equal and determinate intervals, and he proclaimed that it was practically, physically and mathematically impossible that the signals could have come from any other place but Cape Lizard.

In the summer of 1902 Mr. Marconi made an interesting comparative test of his first (coherer) system and his second (magnetic detector) system. The ship "Carlo Alberto" was fitted out with both sets of receiving apparatus. By previous arrangement a set of signals from the Poldhu station was to be sent out at certain hours of the day. As the voyage toward Kronstadt proceeded the signals diminished in strength, and at a distance of 900 kilometers were not perceptible during the day. At night, however, they continued to be received by both systems until the port of Kronstadt was reached, when only the magnetic detector responded, and that only feebly. The disturbing action of daylight was very marked in these tests.

Having received an invitation from the Canadian Government to continue his experiments in Canada, Marconi erected a large station at Table Head, on the island of Cape Breton, at the mouth of Glace Bay, and 3,800 kilometers from Poldhu. On Dec. 20, 1902, Mr. Marconi sent the first radiograms across the Atlantic to the Kings of England and Italy. Shortly afterward another station was erected at Cape Cod, in Massachusetts, the distance to the Poldhu station being 3,200 miles, or 660 miles further than the Glace Bay station. On Jan. 16, 1903, a complete

radiogram was sent by President Roosevelt to the King of England.

Professor Fessenden commenced in 1897 the development of the system which is now the property of the National Electric Signaling Company. For two years he was engaged by the United States Government for special research in the subject, and had the advantages of all the resources of a government department at his command. His inventions are very numerous, and in many respects original, and his results show a precision and practicality not attained by many other experimenters in the same field.

Magnetic, thermal and electrolytic detectors, methods of exact tuning, and even wireless telephony, are covered by Fessenden's patents. Among these, perhaps that which has contributed most to the success of the system is the barretter. In its original form this was a thermal receiver, depending for its action on the change of resistance in a very fine platinum wire when carrying the jig current. Latterly the continuous wire has been discarded in favor of an electrolytic coil, one electrode of which is an extremely fine point. The apparatus has been described more fully under wave detectors. An important feature of this system, which greatly aids secrecy of transmission, is the arrangement of the sending key, which does not break the circuit, but merely alters the wave length of the waves given out, by cutting out some inductance. Thus, unless a receiving station is tuned with extreme accuracy to the transmitter, it will receive, instead of signals, only a long, continuous dash; hence only a very sharply tuned receiver will receive a message at all. In the latest forms of apparatus the difference in frequency between the waves sent out during spaces and those sent as signals is only ¼ per cent.; interception by rivals is, therefore, almost impossible. Fessenden is apparently the first to use an aerial consist-

installation was of the simplest character, consisting of a receiving station only. The aerial line was maintained at a height of about 400 feet by means of a kite.

Marconi had already agreed with the station at Poldhu that every day, at six o'clock in the evening, a long series of letter S should be sent. This letter, in the Morse alphabet, consists of three dots.

The message was received telephonically. On the 12th of December, 1901, Marconi announced that he had received the different S's at equal and determinate intervals, and he proclaimed that it was practically, physically and mathematically impossible that the signals could have come from any other place but Cape Lizard.

In the summer of 1902 Mr. Marconi made an interesting comparative test of his first (coherer) system and his second (magnetic detector) system. The ship "Carlo Alberto" was fitted out with both sets of receiving apparatus. By previous arrangement a set of signals from the Poldhu station was to be sent out at certain hours of the day. As the voyage toward Kronstadt proceeded the signals diminished in strength, and at a distance of 900 kilometers were not perceptible during the day. At night, however, they continued to be received by both systems until the port of Kronstadt was reached, when only the magnetic detector responded, and that only feebly. The disturbing action of daylight was very marked in these tests.

Having received an invitation from the Canadian Government to continue his experiments in Canada, Marconi erected a large station at Table Head, on the island of Cape Breton, at the mouth of Glace Bay, and 3,800 kilometers from Poldhu. On Dec. 20, 1902, Mr. Marconi sent the first radiograms across the Atlantic to the Kings of England and Italy. Shortly afterward another station was erected at Cape Cod, in Massachusetts, the distance to the Poldhu station being 3,200 miles, or 660 miles further than the Glace Bay station. On Jan. 16, 1903, a complete

radiogram was sent by President Roosevelt to the King of England.

Professor Fessenden commenced in 1897 the development of the system which is now the property of the National Electric Signaling Company. For two years he was engaged by the United States Government for special research in the subject, and had the advantages of all the resources of a government department at his command. His inventions are very numerous, and in many respects original, and his results show a precision and practicality not attained by many other experimenters in the same field.

Magnetic, thermal and electrolytic detectors, methods of exact tuning, and even wireless telephony, are covered by Fessenden's patents. Among these, perhaps that which has contributed most to the success of the system is the barretter. In its original form this was a thermal receiver, depending for its action on the change of resistance in a very fine platinum wire when carrying the jig current. Latterly the continuous wire has been discarded in favor of an electrolytic coil, one electrode of which is an extremely fine point. The apparatus has been described more fully under wave detectors. An important feature of this system, which greatly aids secrecy of transmission, is the arrangement of the sending key, which does not break the circuit, but merely alters the wave length of the waves given out, by cutting out some inductance. Thus, unless a receiving station is tuned with extreme accuracy to the transmitter, it will receive, instead of signals, only a long, continuous dash; hence only a very sharply tuned receiver will receive a message at all. In the latest forms of apparatus the difference in frequency between the waves sent out during spaces and those sent as signals is only ¼ per cent.; interception by rivals is, therefore, almost impossible. Fessenden is apparently the first to use an aerial consist-

ing of a steel tube standing on an insulating foundation, and held in position by insulated stays.

The following guarantees are made for the Fessenden system by the holding company. Guarantee for distance: 1 kw. sets, 250 miles; 5 kw. sets, 400 miles; 20 kw. sets, 700 to 750 miles. Guarantee for the preventer, used to prevent other sending stations from interfering with the receipt of messages.

"Where the distance of the interfering station from the receiving station is more than 1 per cent. of the distance between the sending and receiving stations, a difference in wave length of 3 per cent. is sufficient to cut out the interference without the signals being appreciably weakened, interfering and sending stations being of equal power."

Guarantee for the secrecy sender: "With our latest form of secrecy sender the variation in wave length is guaranteed to be only ¼ per cent. between space and dots. We guarantee that no other system can read the messages."

Guarantee for wave measurer: "We guarantee this device to be capable of detecting difference of wave length of ¼ per cent., and to be capable of measuring wave lengths at a distance from the sending station."

There are also devices whereby atmospheric discharges will not interfere with reception, and a device for modifying the intensity of emitted waves without altering their length communicate with near-by stations.

A report giving a description of the Fessenden system, as applied to transatlantic signaling between Massachusetts and Scotland may be of interest here:

"The power is developed by a boiler-engine-alternator equipment having a maximum capacity of 25 kw., 60 cycles current. A transformer steps up the voltage to about 25,000, thus charging the condensers, which are discharged by means of a gap adjustable so as to effect the discharge at any desired point of the cycle.

"The receiver used is the liquid barretter in its latest form. The aerial is formed by a tower extending to a height of 415 feet above the ground-level, and supporting a sort of umbrella formed of wires at its top. The tower is essentially a steel tube 3 feet in diameter, supported every 100 feet of its height by a set of four steel guys, there being thus sixteen guys in all. The tower is pivoted at its base on a ball-and-socket joint, and is insulated from the ground for a voltage of 150,000. The guys are insulated from the tower as well as from the ground; besides, they are divided into 50-foot sections by means of strain insulators. One of the most serious problems to be solved was the construction of these strain insulators, which, while capable of safely transmitting the maximum stress of about 20,000 pounds, also resist an electrical tension of 15,000 volts each. The maximum deflection of the top of the tower in a 90-mile hurricane is computed to be 15½ inches. A wave chute containing over 100 miles of wire, and extending over six acres, is a very essential feature of the installation.

"On January 3, 1906, the first signals were received from the American side, and shortly afterward communication was established, so that messages were freely exchanged at night. The intensity of the signals received by telephone was at times so great that the messages could easily be read with the diaphragm three inches from the ears of the operator. A station twenty miles distant from Brant Rock, using about 30 kw., and sending on a wave length differing not much more than 3 per cent. from that of the Scottish station, was cut out while messages were received from Machrihanish."

A system differing in many respects from the other systems has been devised by Sir Oliver Lodge and Dr. Muirhead. The rotating steel disk coherer described under wave detectors is used by them. Another feature is the use of two capacity areas at both sending and receiv-

ing stations, by the adjustment of which they may be brought into tune.

This system has been installed in many places with great success, and altho it has not yet operated over such distances as the Marconi and Fessenden systems, it compares favorably with them in syntonizing power, and has the advantage of using the siphon recorder.

The Telefunken System is based on the patents of Professors Slaby and Braun and of Count von Arco. It may be considered as striking a mean between the earlier systems of Marconi and Lodge-Muirhead, tho of course with many variations and elaborations in detail. A system of wires, similar to those used by Marconi, forms the aerial, and the earth connection is given by a large capacity, as in the Lodge-Muirhead apparatus. A coherer and receiving circuit in many respects similar to the Marconi arrangement is employed.

The De Forest system has had quite an extended commercial application, especially in the United States. It has the advantage of very rapid signaling, 25 to 30 words per minute having been reached. Communication by this system has been established between Manhattan Beach, New York, and Colon, Panama, a distance of 2,170 miles.

The extension of wireless telegraphy and the study of the relations of electrical discharges in radio-active bodies bids fair to be the most fruitful of the fields of the immediate future. The Age has been well called the Age of Electricity, and much amazement ever is expressed that Man should utilize so well a force concerning which he knows so little. The complete understanding of the phenomena of atomic force and of radio-activity may go far to unlock many of the closed doors of Nature, and the electrical scientist of to-day is steadily approaching that understanding.